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JUH-1H ICE PHOBIC COATING ICING TESTS.

FINAL REPORT.

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UNITED STATES ARMY AVIATION ENGINEERING FLIGHT ACTIVITY
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DEPARTMENT OF THE ARMY
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DRDAV-DI

SUBJECT: Directorate for Development and Qualification Position on the
Final Report of USAAEFA Project No. 79-02, JUH-1H Ice Phobic
Coating Icing Tests

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1. The purpose of this letter is to establish the Directorate for Development and Qualification position on the subject report.

2. This Directorate agrees with the report conclusions and recommendations. However, the following comments are provided to clarify the conclusions and recommendations and are directed to the report paragraphs as indicated:

a. Paragraph 30a. While test results indicate that an icing capability exists for the UH-1H with ice phobic compound coated rotor blades, insufficient testing was conducted to substantiate an icing environment which is certain to be safe. From previous tests, the UH-1H is known to have very limited capability to operate in ice with standard unprotected blades and flight in forecast icing is not recommended. Significantly, more flight testing of the UH-1H with uncoated and ice phobic compound coated rotor blades is required and will be conducted during the 1980/81 icing season. This should allow for coated rotor blades under icing conditions. Consequently, the data contained in this report will be used to supplement future test data.

b. Paragraph 30b. The manhours required to apply the ice phobics compound was apparently excessive. The Applied Technology Laboratory (ATL) is still evaluating methods for reducing the difficulties in applying the ice phobic compound and intends to have a new method during the 1980/81 icing season.

c. Paragraph 31. While no test limits were reached during testing, it is considered that sufficient testing was not conducted to adequately define the magnitude of improvement which ice phobic compound coated blades offer for the UH-1H. Considerably more testing is planned for the 1980/81 icing season tests.

d. Paragraph 32. The roll-on application technique was the best method for applying a uniform ice phobic compound coating during the testing. However, improved methods may be utilized during the 1980/81 icing season tests.

DRDAV-DI

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Coating Icing Tests

e. Paragraphs 33 and 34. The limited testing conducted indicated that the LWC indicators and the IRU were inadequate for determining icing envelope limits. While there are operational problems associated with the LWC indicators and the IRU, it is considered that insufficient testing was conducted during this project to rule out their potential for future evaluations. This Directorate still feels that the LWC indicator offers a potential for providing useful icing severity information to the pilot even though an average icing severity level is not displayed. The LWC indicator can still present to the pilot the peak icing severity level encountered during a flight, and this information can be related to an icing capability as well as being used to establish an icing envelope.

f. Paragraphs 35 and 36. This Directorate agrees with the recommendations. Additional testing of the ice phobic compounds will be conducted during the 1980/81 icing season. Testing will be expanded to include baseline uncoated blade data as well as coated blade data.

3. For existing inservice aircraft where the incorporation of heated rotor blades would be quite expensive, coatings remain an attractive method of increasing capability at a low cost, thus further testing is recommended. Of equal importance is the development of methods to inform the pilot of the icing conditions which are being encountered so that limits of safe operation will not be exceeded.

FOR THE COMMANDER:

11/11/81
CHARLES C. CRAWFORD, JR.
Director of Development
and Qualification

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)		
Natural and artificial icing tests were conducted on a JUH-1H helicopter, in the vicinity of St. Paul, Minnesota, from 12 January to 26 March 1980. An ice phobic coating was applied to both the main and tail rotor blades. A total of 4.0 productive hours were flown in the artificial environment, and 9.3 hours in natural icing conditions. Artificial tests were conducted utilizing the Helicopter Icing Spray System (HISS) with ambient temperatures ranging from -6 to -23°C, and relative humidities of 60 to 90 percent. Natural icing tests were conducted within the ambient temperature range of -2 to -12.5°C, with liquid water contents (LWC) ranging from 0.1 to 0.32 gm/m ³ . The artificial icing tests verified proper operation of the test helicopter ice protection system for use as a safety device in		

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subsequent tests. Natural icing tests were conducted to determine the operational potential of General Electric Corporation G661 ice phobic compound and to gather data to aid in defining icing phenomenon and ice protection equipment design requirements. Due to insufficient quantitative baseline UH-1H rotor blade icing data, it was not possible to determine if the G661 ice phobic compound affected the operational icing capability of the UH-1H helicopter. Nine minor asymmetric ice sheds were encountered, however, no predetermined limit conditions were reached during testing. Excessive equipment and man-hour requirements degrade the practicality of G661 use. The LWC indicators were not adequate to determine ice accretion level and the Integrating Rate Unit (IRU) did not provide a repeatable cue of impending asymmetric ice shed.

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INTRODUCTION

BACKGROUND

1. The US Army need for an all-weather operational capability in its helicopter fleet has led to extensive icing tests since 1973 in both natural and artificial conditions. The US Army Aviation Engineering Flight Activity (USAAEFA) utilizes a CH-47C helicopter modified with a Helicopter Icing Spray System (HISS), (app B) to produce the icing cloud used during artificial icing tests.

2. Results of prior tests indicated that the HISS did not produce a cloud representative of the natural environment. Therefore, the HISS was modified to provide a more suitable simulation of natural icing conditions. Initial testing during the 1979-80 icing season was conducted to evaluate and document the HISS modification. Results of this evaluation are included in reference 1, appendix A. Additional artificial and natural icing data are included in reference 2.

3. The Applied Technology Laboratory (ATL), US Army Aviation Research and Development Command (AVRADCOM) has investigated ice phobic coatings as an interim solution to the helicopter rotor blade icing problem. Laboratory and artificial icing tests on ice phobic coatings have been previously conducted. To further evaluate the effectiveness of ice phobic coatings and obtain icing flight data relative to ATL and Federal Aviation Agency (FAA) research and development requirements, AVRADCOM directed USAAEFA to conduct icing tests on a modified UH-1H helicopter (ref 3, app A).

TEST OBJECTIVES

4. The objectives of the test program were:

a. To provide data to AVRADCOM for establishing a natural icing flight envelope for the UH-1 helicopter utilizing an ice phobic coating for main and tail rotor blade ice protection.

b. To acquire research and development data for better understanding of icing phenomenon, ice protection equipment design, and helicopter icing airworthiness qualification requirements.

c. To evaluate the effect of rain, freezing rain, and snow on ice phobic coating life.

DESCRIPTION

5. The test JUH-1H helicopter (USA S/N 7016318) was manufactured by Bell Helicopter, Textron and incorporated an electrothermal rotor ice protection system and UH-1H (Kit A) ice protection system (ref 4, app A). The combination of these systems is referred to in this report as the ice protection system (IPS) (app B). A detailed description of the helicopter is contained in the operator's manual (ref 5, app A). Special equipment installed on the helicopter included a KIT B Infrared (IR) suppressor; Meteorology Research, Inc (MRI) laser nephelometers mounted on both sides of the cabin area; a dew-point hygrometer mounted on the cabin roof; and a hub mounted camera. A detailed description of special equipment and test instrumentation installed on the aircraft is contained in appendix C. A description of

the HISS is contained in appendix B and also in reference 1, appendix A.

6. The ice phobic compound tested was G661, manufactured by General Electric Corporation. The compound is a silicone based, high viscosity polydimethylsiloxane fluid designed to promote early ice shedding.

TEST SCOPE

7. Icing tests were conducted in the vicinity of St. Paul, Minnesota, from 12 January to 26 March 1980. Seven artificial icing flights were conducted with 4.0 productive hours of immersion in the HISS plume. Fourteen flights were conducted for a total of 9.3 hours in natural icing conditions. Natural icing tests were conducted at an ambient temperature range of -2 to -12.5°C with a liquid water content (LWC) range of 0.1 to 0.32 gm/m³ as determined from the MRI laser nephelometer. A summary of the natural icing test conditions is contained in table 1, appendix E. The target airspeed during all tests was 90 knots calibrated airspeed (KCAS) with a constant rotor speed of 324 RPM. Takeoff gross weight was approximately 8500 pounds with a mid range longitudinal center of gravity (CG) station (Fuselage Station 139.0). All flights were conducted with coated blades and thus no comparison between the ice accretion and shedding characteristics of coated versus uncoated blades could be made. Flight limitations contained in the operator's manual and the airworthiness release (ref 6, app A) were observed throughout the testing.

TEST METHODOLOGY

8. Initial flights under artificial icing conditions were conducted to verify proper operation of the Ice Protection System (IPS) which was used as a safety system during subsequent natural icing flights. After IPS operation was confirmed by the hub mounted camera and the chase aircraft, additional artificial icing flights were flown to calibrate the HISS (refs 1,2, app A).

9. Following IPS verification, natural icing flights were conducted to maximize airframe and rotor system ice exposure. Previous year's testing had established that flight in icing conditions could be maintained until one of the following "limit conditions" was reached: significant asymmetric shed as evidenced by an appreciable increase in aircraft lateral vibrations; excessive (5 psi) torque rise; total obscuration of forward visibility by ice accretion on both windshields; or excessive (10 inch H₂O) engine inlet screen differential pressure change. Within the icing environment encountered in this years testing, none of these conditions were reached. Therefore, the aircraft was flown in the icing conditions until fuel requirements necessitated returning to base.

10. Minneapolis Radar Approach control, or Minneapolis Center provided aircraft separation and vectoring for both test and chase helicopters during all natural icing flights. Photo coverage of the test aircraft was provided from the chase helicopter as soon as possible after leaving the icing environment.

11. Laser nephelometers were used as the basis for measuring the physical characteristics (droplet concentration, size distribution, LWC) of the natural icing environ-

ment. Additionally, one Rosemount and two Leigh (MK 10 and MK 12) ice detection and accretion rate systems, plus a USAAEFA-fabricated visual ice accretion probe were used to measure the rate of accretion and the incremental accumulation of ice. When practicable, in-flight and post flight photography were used to document test results. Data were recorded by hand and on magnetic tape.

12. The ice phobic compound was applied to the main and tail rotor blades for all natural and artificial icing flights. The compound was removed from the blades following each flight, and a fresh coating applied.

RESULTS AND DISCUSSION

GENERAL

13. Natural icing tests were conducted on a UH-1H helicopter with ice phobic coated main and tail rotor blades to determine the operational potential of an ice phobic compound. Ice phobic application techniques, erosion, flow, ice accretion and shedding characteristics were evaluated. Data were also obtained to aid in defining icing phenomenon and ice protection equipment design requirements. Excessive equipment and man-hour requirements degrade the practicality of G661 use. Nine minor asymmetric sheds were experienced, however no predetermined limit conditions were reached. Due to a lack of uncoated blade baseline data, it was not possible to determine if the G661 ice phobic compound affected the operational icing capability of the UH-1H helicopter. The LWC indicators were not adequate for determining the average icing severity level and the IRU did not provide a reliable cue of impending asymmetric ice shed.

ICE PHOBIC EVALUATION

Application Procedures

14. The ice phobic compound was prepared and applied inside a heated maintenance hangar using application techniques developed on site. Several techniques were evaluated prior to the first flight. These included a wipe-on technique using a paint applicator, a brush-on technique using a paint brush, and a roll-on technique using a 9-inch nylon paint roller. The roll-on technique was found to be the cleanest, quickest, and easiest method of applying a uniform coating, and was used for all subsequent testing.

15. The roll-on technique required dilution of 1.5 pints of G661 ice phobic compound with 1/2 pint toluene to obtain the proper consistency for application. Prior to each application, the previous ice phobic coating was removed from the blades using disposable paper shop towels soaked with toluene. The Army hydraulically adjustable B-1 maintenance stands were used to facilitate application with a wooden shim placed between the mast and the main rotor yoke assembly to prevent main rotor blade flapping during application. The coating was applied to the top and bottom surfaces of both the main and tail rotor blades. A coating of approximately 1/32-inch thickness was applied from the leading edge 9 inches aft along the entire span of top and bottom blade surfaces. Preparation of the compound, removing the old coating, and applying a fresh coat of ice phobics required approximately 3 man-hours to complete.

16. Previous testing with ice phobic compounds had identified a requirement for personal protective equipment. During initial roll-on applications of the G661 compound, personnel wore rubber gloves to prevent skin irritation and clear unvented eye goggles to prevent eye irritation. It was soon determined that a protective mask was needed to prevent headaches and a 3M Company Model 8712 organic vapor respirator was used.

17. Since the application of an ice phobic compound is intended as an expedient means to allow otherwise unprotected aircraft to fly in icing conditions, the ease of preparation and application must be considered. The need for maintenance stands or ladders, protective equipment for application personnel, and the appreciable man-hours required for preparation and application significantly degrade the

practicality of G661 ice phobic use. Means of simplifying the preparation and application procedures of G661 should be developed.

Erosion and Flow Characteristics

18. The erosion and flow characteristics of the G661 ice phobic compound were documented after each flight. A strip of 2 inch tape (3M No. 355) was pressed to the rotor blade surface to qualitatively evaluate its adhesive strength. A rating was assigned to the coating in accordance with table 1.

Table 1. Adhesion Characteristics Ratings

Rating	Properties
Excellent	(1) Blade surface oily to touch (2) Tape will not adhere to blade surface
Poor	(1) Blade surface not oily to touch (2) Tape adheres to the blade surface similarly to a clean dry blade surface

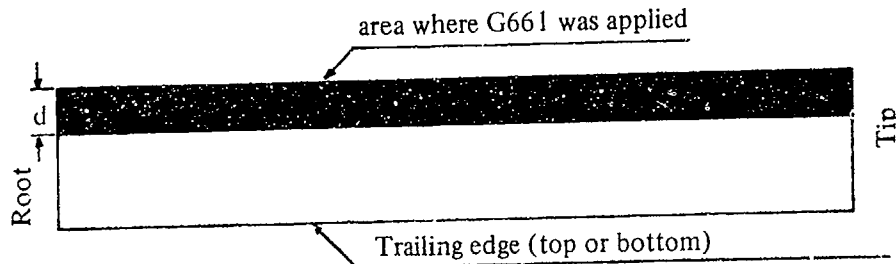
19. The erosion and flow characteristics of the G661 ice phobic compound were essentially the same for all flights, and figure A shows a sketch of a typical pattern. The adhesion characteristics of the leading edge of both main and tail rotor blades (eroded area, figure A) were poor, with all other treated areas considered excellent. Adhesion characteristics were the same for both top and bottom surfaces of the main and tail rotor blades. No testing was accomplished in rain, freezing rain, or snow.

Ice Accretion and Shedding Characteristics

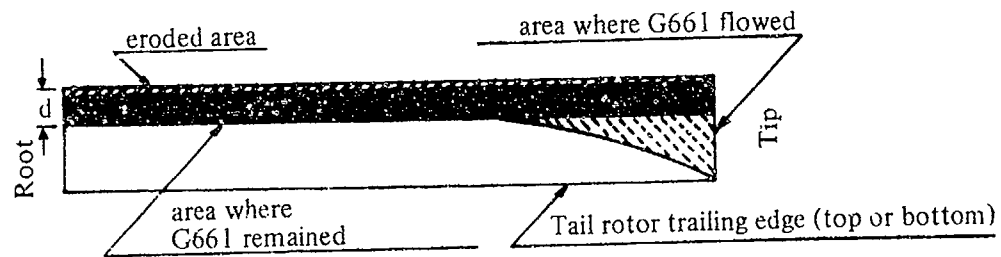
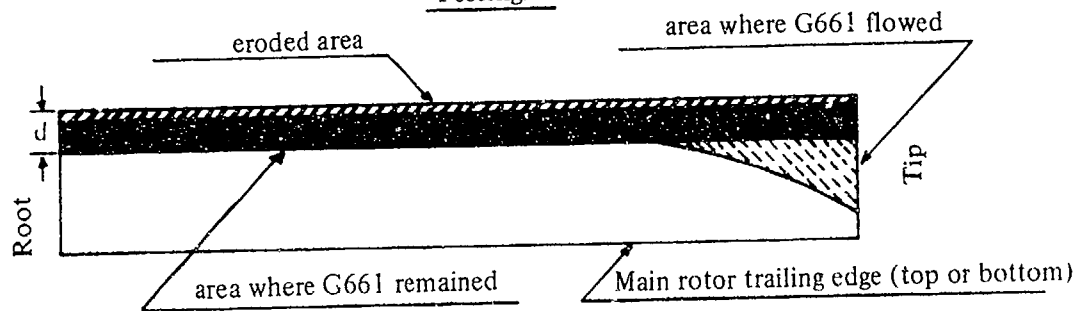
20. Ice accretion and shedding characteristics of the main and tail rotor blades coated with G661 ice phobic compound were evaluated during 14 natural icing flights. Table 1, appendix E shows a summary of the natural icing encountered during testing. Actual in-cloud main rotor ice accretion was initially documented by use of a main rotor hub mounted camera. However, only limited hub camera data were obtained due to camera maintenance problems. This necessitated use of photographs taken from the chase aircraft after exiting the icing conditions and postflight visual inspections to document ice accretion.

21. No ice was noted on the tail rotor blades. The limited hub camera film available showed 1/4 inch to 1/2 inch thick ice accreted on the leading edge of the main rotor blade from the root to the tip, however, no appreciable torque rise could be associated with this particular buildup. The maximum torque rise encountered was 3 psi (after correcting for fuel burnoff). No predetermined test limits were reached during testing, however, nine minor asymmetric sheds occurred. The lateral

Preflight
(Both Main and Tail Rotor Blades)



Postflight



d = 9 inches for main rotor,
5 inches for tail rotor

Figure A. Typical Erosion and Flow Pattern of G661

vibrations resulting from these sheds were slight to moderate (VRS 3 to 4), with a maximum amplitude of 0.19 g at a frequency 5.4 hertz. All sheds were of short duration (approx 15 seconds) and caused minimal concern to the aircrew. Time from cloud entry to asymmetric shed varied from 5 to 36 minutes and appeared to be a function of average LWC as illustrated in figure 1, appendix E. However, less than 50 percent of the natural icing encounters produced an asymmetric shed, providing little repeatable quantitative data.

22. Previous testing of the unprotected UH-1H helicopter had not resulted in an operational icing capability. Since uncoated blade testing was not accomplished this year and insufficient data were available from prior testing, it was not possible to determine any changes in operational icing capability attributable to use of G661. Further testing with coated and uncoated rotor blades should be accomplished to determine changes in icing capability with ice phobic coated rotor blades.

ICE PROTECTION EQUIPMENT EVALUATION

General

23. The ice protection equipment installed on the test helicopter was evaluated throughout the test program. This equipment included the main rotor blade deice system, stabilizer bar and windshield anti-ice systems, and various ice detectors/displays. The main rotor blade deice, stabilizer bar and windshield anti-ice systems were utilized as a back up safety system. The ice detectors and LWC/IRU displays were evaluated as cockpit instrumentation which would provide the basis for an operational pilot of an unprotected aircraft to remain within a natural icing envelope.

Deice System (Main Rotor Blade)

24. The main rotor blade deice system was operated in a standby mode to provide emergency deice capability should significant vibrations be encountered following asymmetric ice sheds. The system was operated in the manual mode with temperature and LWC inputs selected through the cockpit controls. Numerous electrical malfunctions of the blade deice system occurred during initial system verification flights, which required on site analysis and repair by the manufacturer. The blade deice system was not required during natural icing flights, however, periodic operational checks were performed with no problems encountered following the manufacturers on site repair.

Anti-ice Systems (Stabilizer Bar and Windshields)

25. Natural icing tests were conducted with the stabilizer bar anti-ice system in the standby mode to provide emergency protection should excessive vibrations due to ice accretion/sheds become a problem. No significant vibrations were encountered and the system functioned properly during periodic operational checks.

26. Natural icing tests were conducted with one windshield electrothermally heated and the other heated by the standard bleed air defog system. Both systems proved effective in both anti-ice and deice modes. Within the icing environment encountered, the electrothermally heated windshields did not increase the capability of the aircraft.

Ice Detector Operation

27. The accuracy and operational capability of all onboard ice detectors were evaluated by comparing time histories of natural icing encounters with LWC calculated from the MRI laser nephelometer droplet distribution data. The MRI calculations are discussed in appendix D. A typical time history of a natural icing encounter is shown in figure 2, appendix E. Reasonably good agreement between the individual sensors was obtained when allowance was made for the different physical locations on the airframe and the corresponding flow fields. Although the LWC indicators appear to give accurate indications at a specific point in time, the value of LWC within a natural icing cloud inherently varies. This variation makes it impossible for the pilot, using a LWC indicator, to determine the average icing severity level, thus precluding proper adherence to an icing envelope specified in terms of LWC and time.

28. The IRU was evaluated as an icing indicator designed to provide an operational pilot cue as aircraft icing limits are approached. The IRU appeared to be working properly; IRU counts varied directly with LWC, at constant immersion time, and varied directly with immersion time, at approximately constant LWC (fig 3, app E). Although no icing limit conditions were met, nine minor asymmetric sheds were experienced. There was, however, poor correlation between the occurrence of an asymmetric shed and IRU counts as shown in table 1, appendix E (flights 14, 18, 25). From the limited data base available, there is insufficient evidence to indicate that an IRU type device will provide an adequate indication of impending sheds.

29. A USAAEFA-fabricated visual ice accretion probe was used to provide the pilot a visual cue of helicopter ice buildup. A detailed description of the probe is included in appendix C. Probe ice accretion data for each natural icing immersion are included in table 1, appendix E. The visual ice accretion probe gave the pilot an indication of when ice began to build on the aircraft, the type of ice buildup, and the approximate rate of buildup. The windshield wipers and OAT probe also have these indications, however the accretion stripes on the visual probe helped to quantify the amount and rate of buildup. No correlation existed between ice accretion buildup on the visual probe, LWC and/or IRU indications, or asymmetric sheds.

CONCLUSIONS

GENERAL

30. The following conclusions were reached upon completion of the natural icing tests of the UH-1H with ice phobic coated rotor blades:

a. Due to a lack of uncoated rotor blade baseline data, it was not possible to determine if the G661 ice phobic compound affected the operational icing capability of the UH-1H helicopter (para 22).

b. Excessive equipment and man-hour requirements degrade the practicality of G661 use (para 17).

SPECIFIC

31. No predetermined test limits were reached during testing, however, nine minor asymmetric sheds were encountered (para 21).

32. The roll on application technique was the cleanest, quickest, and easiest method for applying a uniform coating of G661 (para 14).

33. The LWC indicators were not adequate for determining the average icing severity level (para 27).

34. The IRU did not provide a repeatable cue of impending asymmetric shed (para 28)

RECOMMENDATIONS

35. Should further testing of ice phobic compounds be conducted, baseline uncoated blade data must be collected to determine changes in icing characteristics attributable to ice phobics.
36. Should further testing warrant fielding of G661, means of simplifying preparation and application procedures should be developed.

APPENDIX A. REFERENCES

1. Letter Report, USAAEFA Project No. 79-02-02, *Helicopter Icing Spray System (HISS) Improvement Evaluation*, unpublished.
2. Report, Meteorology Research, Inc., No. MRI 80 dFR-1748, *Droplet Size and Liquid Water Characteristics of the USAAEFA (CH-47) Helicopter Spray System and Natural Clouds as Sampled by a JUH-1H Helicopter*, April 1980.
3. Letter, AVRADCOM, DRDAV-EQI, 18 April 1979, subject: HISS Improvement and JUH-1H Ice Phobic Coating Natural and Artificial Icing Test, AVRADCOM/AEFA Test Request, Project No. 79-02.
4. Supplement to Technical Manual, TM 55-1520-210-10, *Operator's Manual, UH-1H Helicopter Serial No. 70-16318, Incorporating an Advanced Ice Protection System and UH-1H Kit A Ice Protection*, 19 July 1978.
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8. Final Report, USAASTA, Project No. 66-04, *Engineering Flight Test, YUH-1H Helicopter*, November 1970.

APPENDIX B. DESCRIPTION

HELICOPTER ICING SPRAY SYSTEM (HISS)

1. The HISS is installed in a modified CH-47C helicopter and consists of an internally mounted 1800 gallon water tank and an external spray boom assembly suspended 19 feet beneath the aircraft from a cross-tube through the cargo compartment. A schematic is shown in figure 1, and a detailed description is given in reference 7, appendix A. Hydraulic actuators rotate the cross-tube to raise and lower the boom assembly. Both the external boom assembly and water supply can be jettisoned in an emergency. The spray boom consists of two 27-foot center sections, vertically separated by 5 feet, and two 17.6-foot outriggers. The outriggers are swept back 20 degrees and angled downward 10 degrees giving a tip to tip boom width of 60 feet. A total of 97 Sonic Development Corporation Sonicore Model 125-HB nozzles are installed on the two center sections. The spray cloud is generated by pumping water at known flow rates from the tank to the nozzles on the boom assembly, using aircraft engine compressor bleed air to atomize the water.

2. A calibrated outside air temperature (OAT) probe and a dew point hygrometer provide accurate temperature and humidity measurement. An aft-facing radar altimeter is mounted at the rear of the HISS to allow positioning the test aircraft at a known standoff distance. Because of gross weight and center of gravity limitations, the aft fuel cells of the helicopter are left empty and only 1500 gallons of water are carried. For icing tests, a chemical dye is added to the water to impart a yellow color to the ice.

3. At the 150 to 250-foot standoff distances used for icing tests, the approximate size of the visible spray cloud is 8 feet deep and 36 feet wide. The measured drop size distribution and liquid water content (LWC) variation of the spray cloud are shown in figures 2 and 3. For a 90 KTAS test condition, the average LWC of the spray cloud was controlled by adjusting the water flow rate as shown in figure 4. This relation was theoretically derived assuming mass conservation (no evaporation) and a uniform water distribution over the cloud cross-sectional area, (258 ft²). However, this line also provides a close fit to averaged LWC data measured in flight at relative humidity conditions above 65% and temperatures below -5°C.

TEST HELICOPTER (GENERAL)

4. In addition to the ice protection provided a basic UH-1H helicopter (pitot-static tube and engine air inlet), the test helicopter incorporates an ice protection system (IPS). The IPS provides protection for the main rotor blades, stabilizer bar/tip weights, pilot/copilot windshields, and tail rotor blades (not operational for this test). Nonstandard features are shown in figure 5.

ICE PROTECTION SYSTEM (IPS)

Power System

5. To supply electrical power to the IPS, the existing direct current (DC) generator has been replaced by a 30 kilovolt-ampere (KVA), 400 hertz alternating current (AC) generator. The AC generator is mounted on the forward accessory pad of the main transmission. Because of the elimination of the main DC generator, the primary source of DC power will be the engine-driven starter/generator. A 200

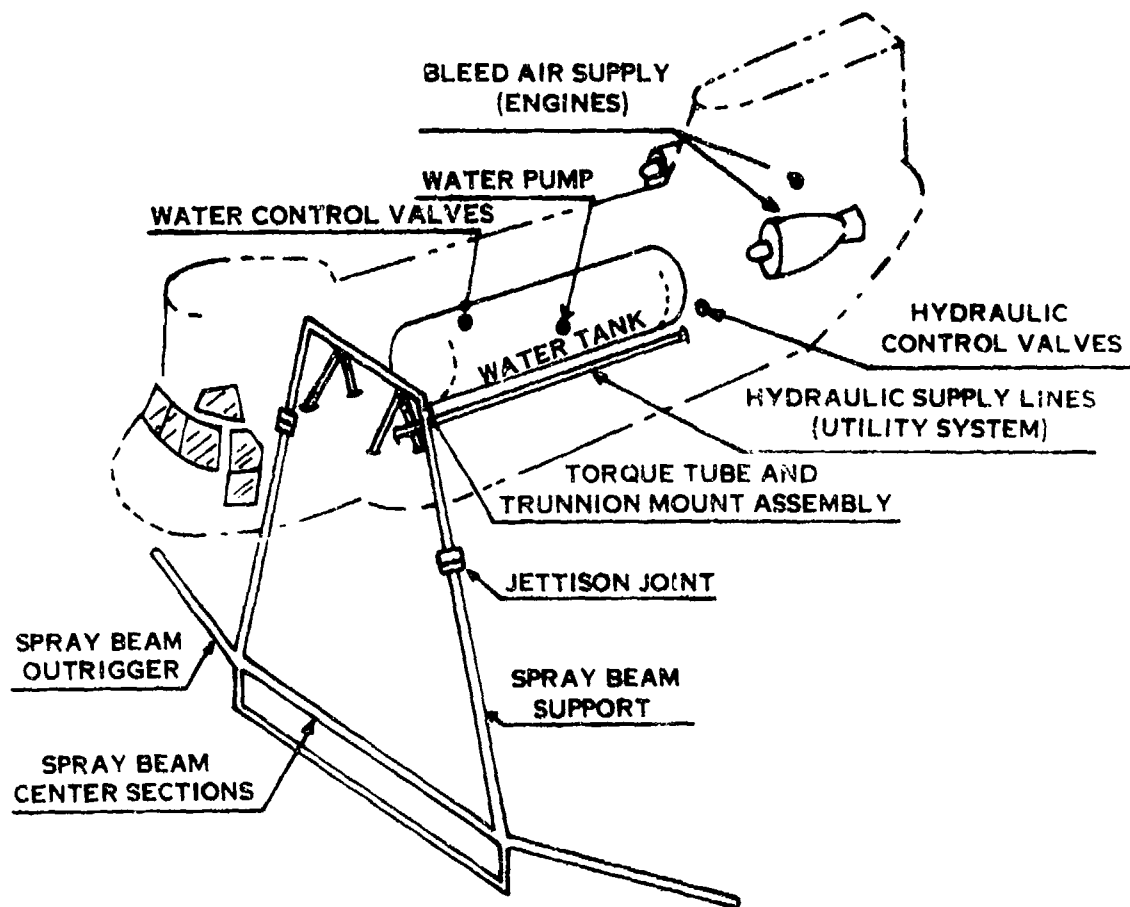


Figure 1. HISS Schematic

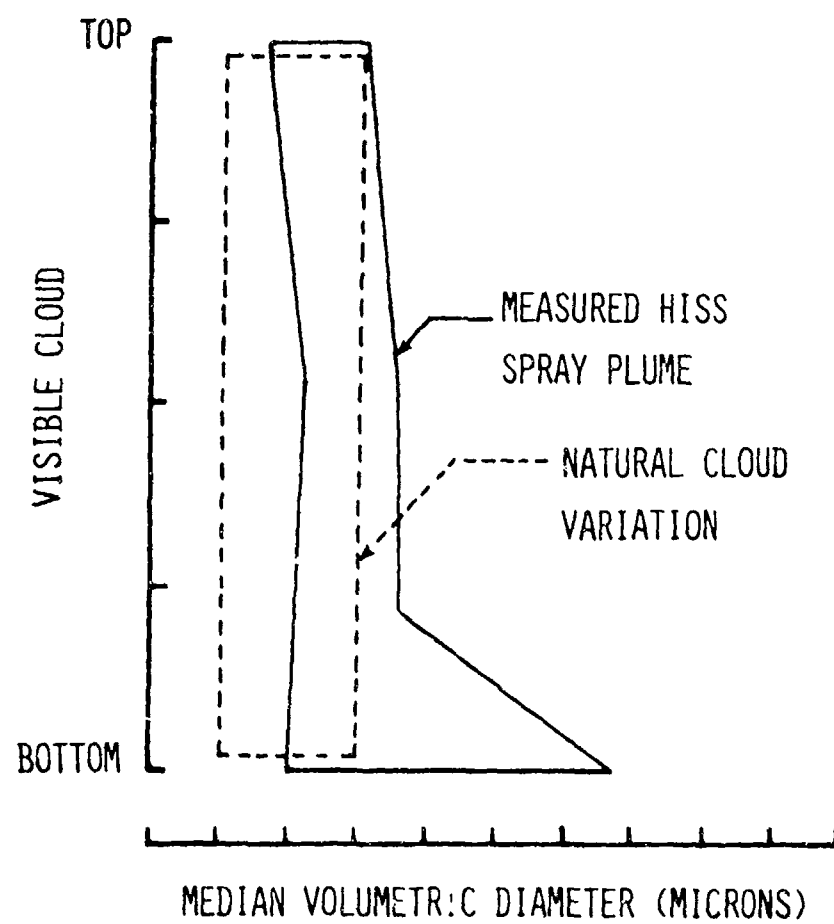


Figure 2. Vertical Variation of Cloud Droplet MVD

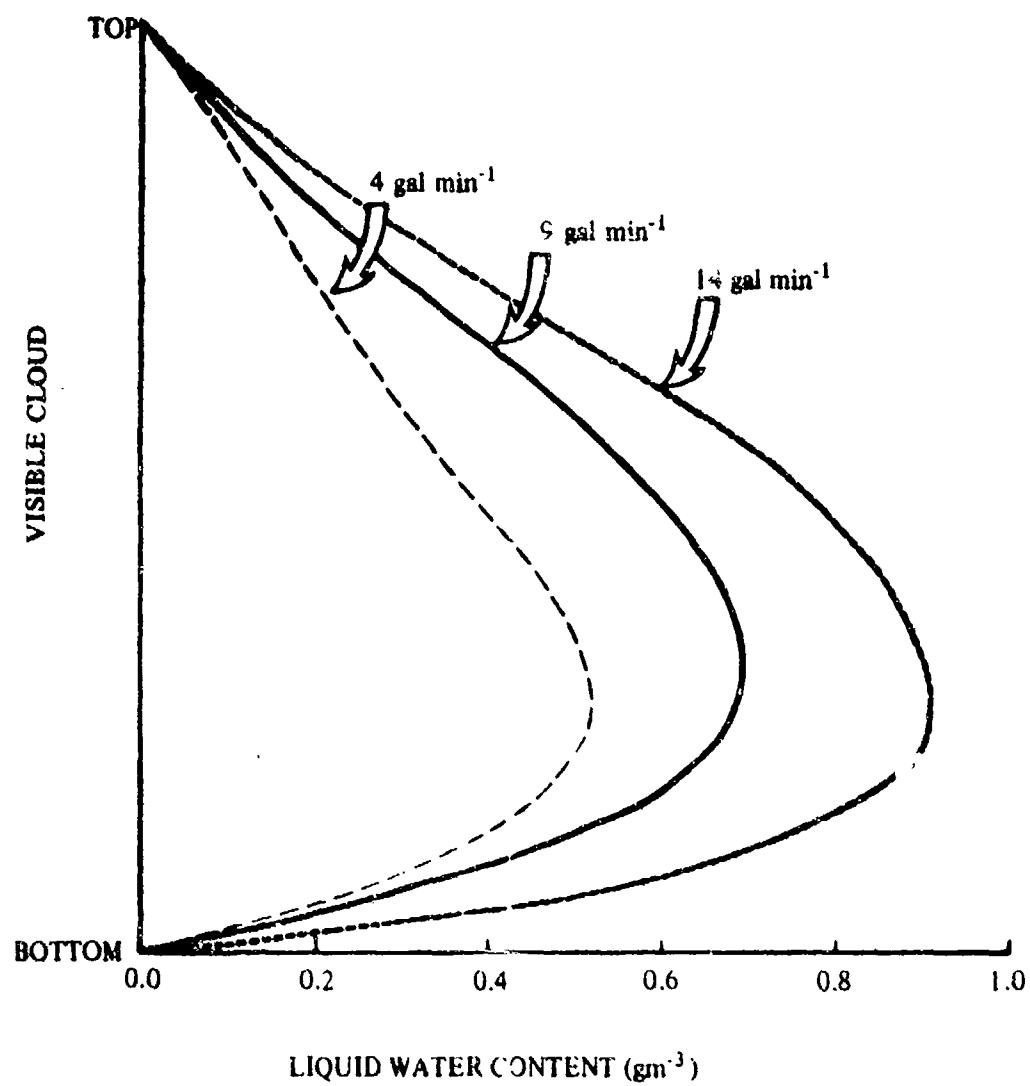


Figure 3. Vertical Variation of Visible Cloud LWC

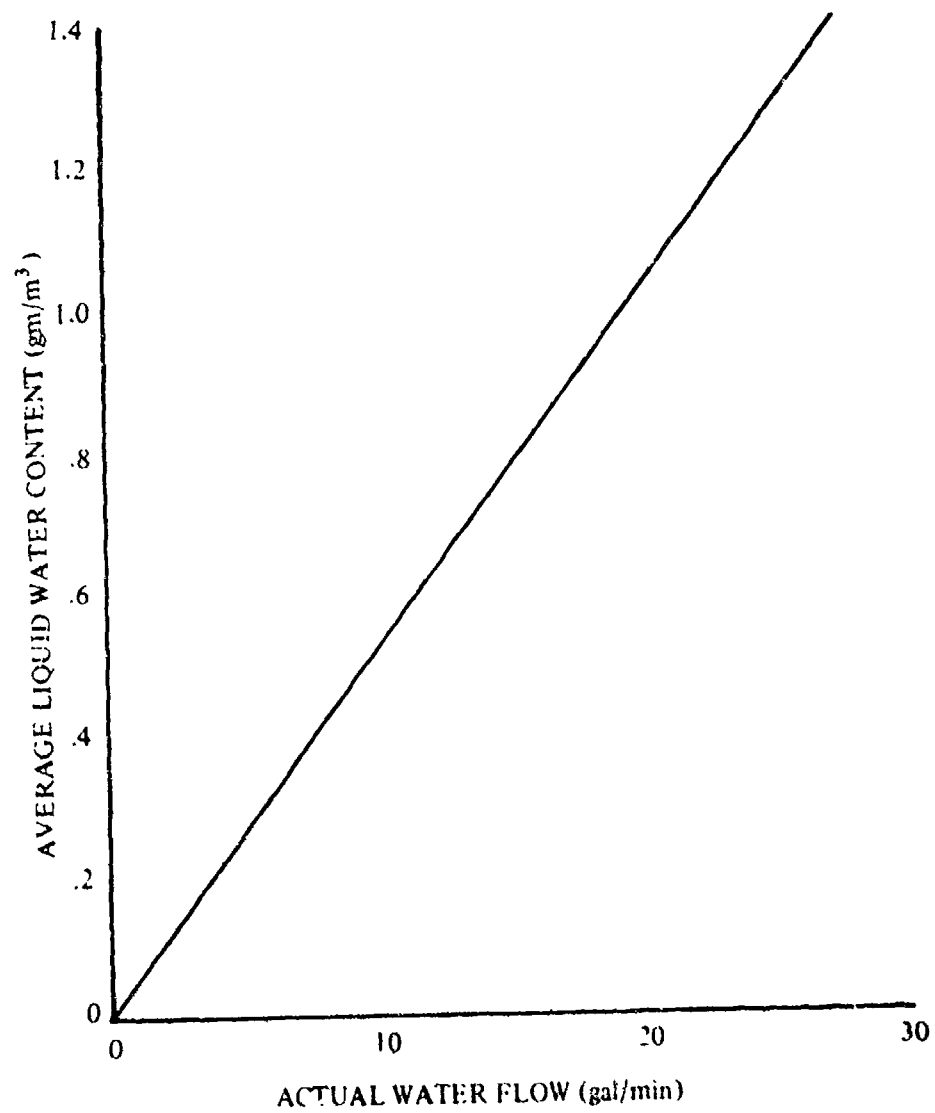


Figure 4. HISS Water Flow vs Icing Cloud LWC

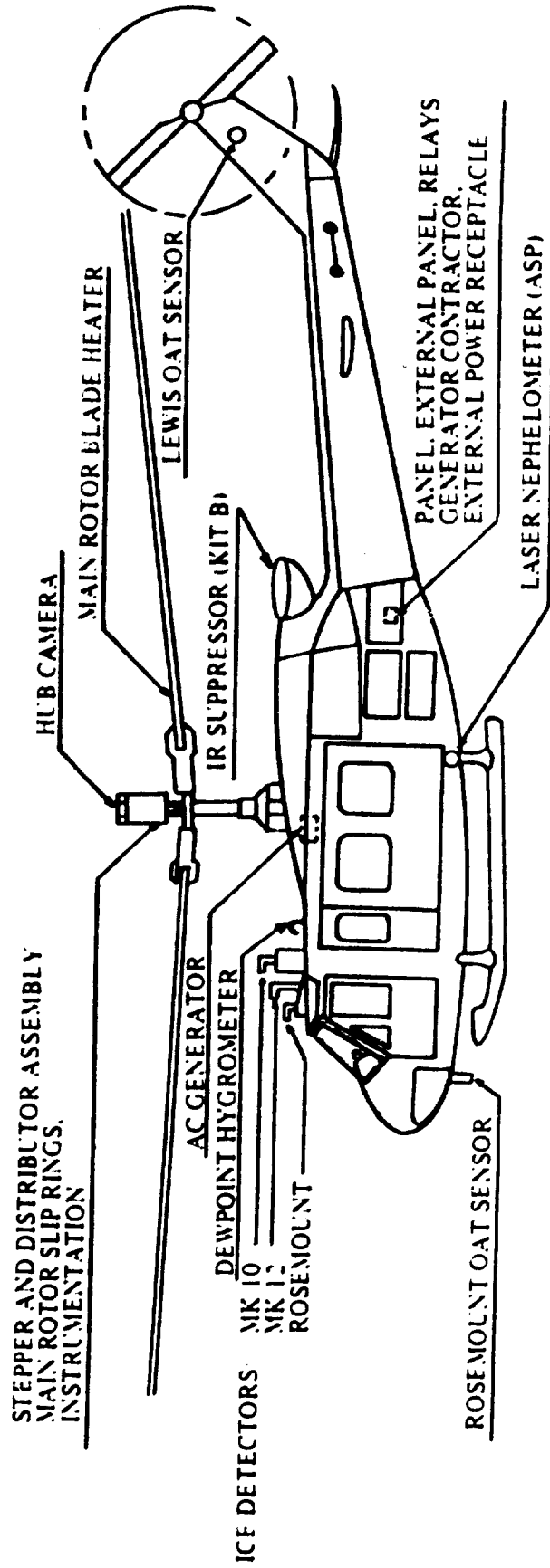
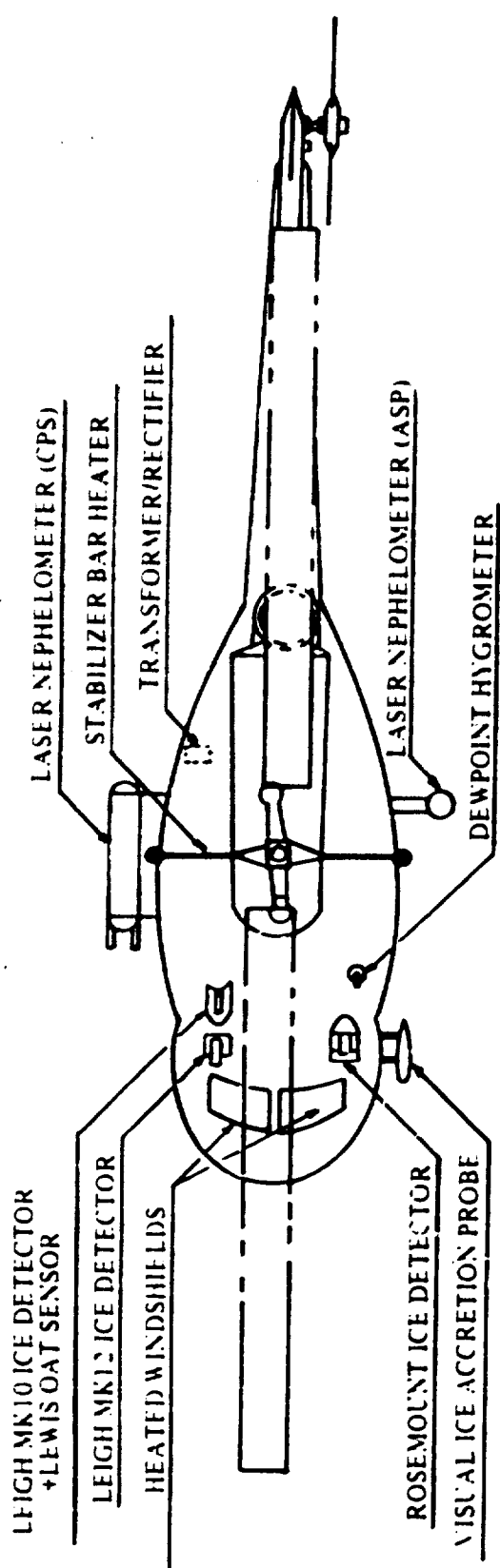


Figure 5. Non-Standard Features

ampere transformer-rectifier to convert AC to DC power is installed as a standby DC system.

System Operation

6. The IPS operation is controlled through the IPS panel (fig 6), IPS control unit (fig 7), and IPS controller (fig 8), all located on the center console. Windshield anti-icing is controlled manually from the IPS panel. Stabilizer bar/tip weights anti-ice is controlled manually from the IPS control unit. Main and tail rotor blade de-ice is controlled either automatically or semiautomatically from the combined operation of the IPS controller and IPS control unit.

a. Automatic mode: In the automatic mode, icing severity signals from the MK 10 ice detector and Lewis OAT probe schedule the operation of main and tail rotor blade heater elements according to predetermined OAT and ice accretion level parameters. The variables involved are individual heater element ON time and dwell time (system OFF time between cycles). The IPS control unit provides an indication (ICING light) when icing conditions are encountered. An icing severity signal from the ice detector and a below freezing OAT signal are required to permit power to be applied to the rotor blades in the automatic mode.

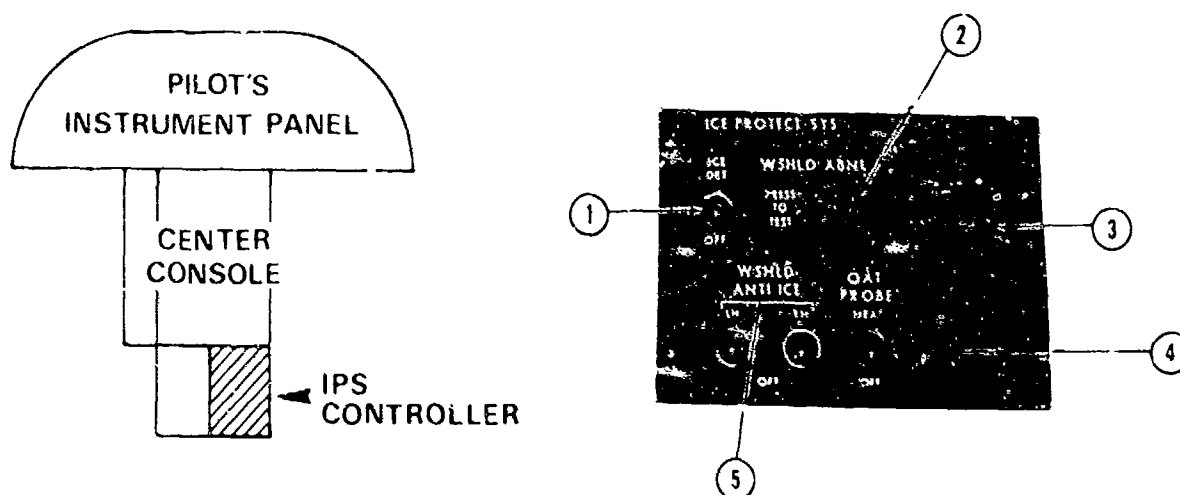
b. Semiautomatic mode: In the semiautomatic mode, the LWC and OAT inputs to the IPS controller are selected by the flight crew through the IPS control unit. This in turn controls the ON time of the deicer heating elements. Manual ground adjustments are also provided to vary heater parameters during optimization of the system.

7. The IPS control unit provides operational control and adjustment capability for the main and tail rotor blade deice and stabilizer bar/tip weight anti-ice through switches located on the control unit. Blade deice ON/OFF time is scheduled as a function of OAT and LWC. Separate indicators for OAT and LWC are incorporated on the control unit head.

8. The IPS controller is an automatic processor which accepts automatic data from the MK 10 ice detector and Lewis OAT probe, or manual data inputs from the IPS control unit. It provides the means for adjusting the heat ON/OFF time of the main rotor and provides system fail indications for main and tail rotor blade heater failure.

Windshield Anti-Icing

9. The pilot and copilot windshields are anti-iced by supplying electrical power to a transparent metallic conductive coating bonded between the laminations of the windshield. Windshield heating is controlled by independent ON/OFF switches located on the IPS panel. Control of windshield temperature is automatic after windshield anti-ice switches are turned on. Three phase AC power is used for heating with a single phase heating each third of the windshield. A temperature sensor located in each windshield provides temperature input to maintain a predetermined temperature range by proportional control of power to the heating elements.



KIT A. ICE PROTECTION SYSTEM PANEL

INDEX	SWITCH OR INDICATOR	FUNCTION
1	Ice Det. On-Off	Turns on the Rosemount Ice Detector
2	WSHLD ABNL	Warning lights illuminate "Left" or "Right" heated glass window abnormal conditions
3	Total Air Temperature Gage	Displays outside air temperature digitally in degrees centigrade
4	OAT Probe Heat On-Off	Provides on-off control of anti-ice heaters on the Rosemount total air temperature probe (Model 102) (Not used in conjunction with non-heated model 172 temperature probe)
5	WSHLD Anti-ice On-Off left and right	Turns on the automatic windshield deice heater controls

Figure 6. IPS Panel

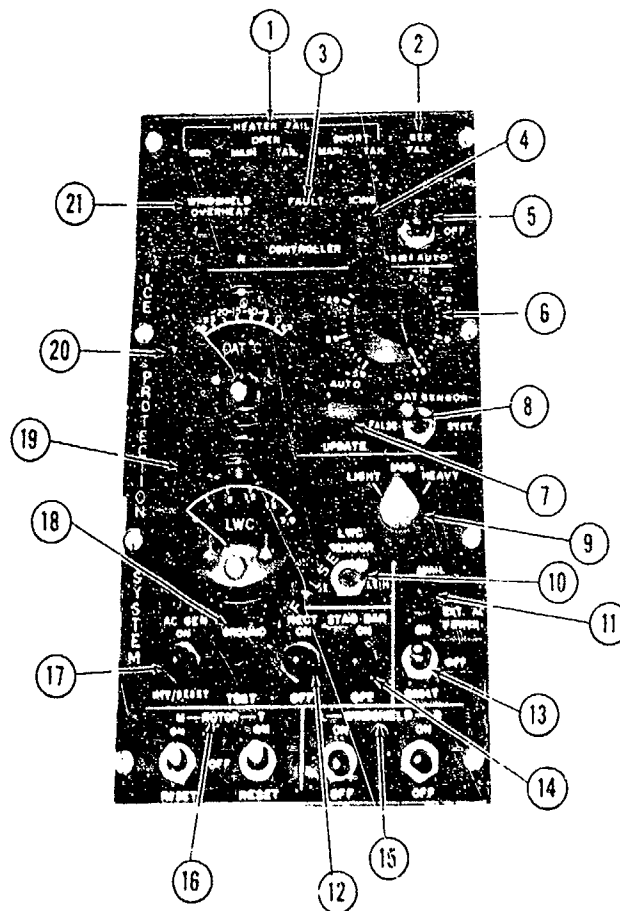
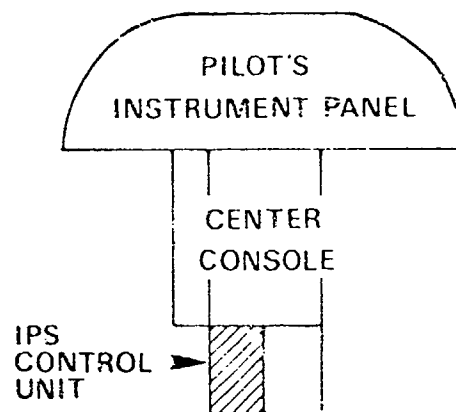


Figure 7. IPS Control Unit

INDEX	SWITCH OR INDICATOR	FUNCTION
1	HEATER FAIL tail	Provides warning of any line-to-ground leakage in the generator system or in the wiring of the main or rotor deicing system, such as a rotor blade element shorting to ground.
	OPEN MAIN TAIL	Provides warning of an open element of open line for main or tail rotor deicing system NOTE The OPEN MAIN/TAIL lamp lights if the MASTER POWER switch on the deicing controller is ON and corresponding ROTOR switch on deicing control unit is ON with AC GEN switch OFF.
	SHORT MAIN TAIL	Provides indication when current is excessive for main or tail rotor on any power phase
	SHORT MAIN	Also provides indication that power switching stepper is out of synchronization.
2	AC GEN FAIL	Deactivated
3	FAULT CONTROLLER	Provides indication when main rotor power doesn't follow time control but stays on
4	ICING	Provides indication that icing conditions are present outside the helicopter when MASTER POWER switch on deicing controller is ON and icing conditions are encountered or a false signal is introduced to simulate icing
5	MODE SWITCH	Allows selection of automatic or semiautomatic operation of ice protection control system. Detented to prevent inadvertent operation
6	OAT SELECTOR	Allows setting outside air temperature into deicing system in semiautomatic mode
7	AUTO UPDATE	Allows initiation of main rotor timer operation. Resets all timers for normal operation to begin again (with zone 1 for main rotor)
8	OAT SENSOR	Allows selection of FALSE or SYST OAT sensor for display on OAT meter and input to the deicing controller

INDEX	SWITCH OR INDICATOR	FUNCTION
9	LWC SELECTOR (LIGHT/MOD/HEAVY)	Allows setting LWC icing condition into system in semiautomatic mode to control OFF times
10	LWC SENSOR	Allows selection of FALSE or LEIGH LWC sensor for display on LWC meter and input to the controller
11	EXT AC PWR AVAIL. LAMP	Provides indication that AC external power is available
12	RECT ON/OFF	Deactivated
13	EXT AC PWR ON/OFF RESET SWITCH	Allows external AC power to be applied to the helicopter
14	STAB BAR ON/OFF	Allows power to be applied to stabilizer bar heating blanket. Detented to prevent inadvertent operation.
15	L-WINDSHIELD>R ON/OFF	Deactivated. Use Kit A panel
16	M-MOTOR-T ON/OFF RESET	Allows power to be applied to either or both main and tail rotor heater elements Allows resetting BITE circuits
17	AC GEN ON OFF/RESET	Deactivated. Use Kit A panel
18	GROUND TEST	Allows overriding of normal timing circuits by a test oscillator to test rotor heating cycle. With normal loads, the main rotor blades will have one operational sequence and the tail rotor blades will have one power on period. The test oscillator is turned off at the end of the main rotor blade sequence.
19	LWC METER	Provides indication of outside liquid water content (LWC) when MASTER POWER switch is ON
20	OAT METER	Provides indication of outside air temperature when MASTER POWER switch is ON
21	WINDSHIELD OVERHEAT L R	Deactivated. Use Kit A panel

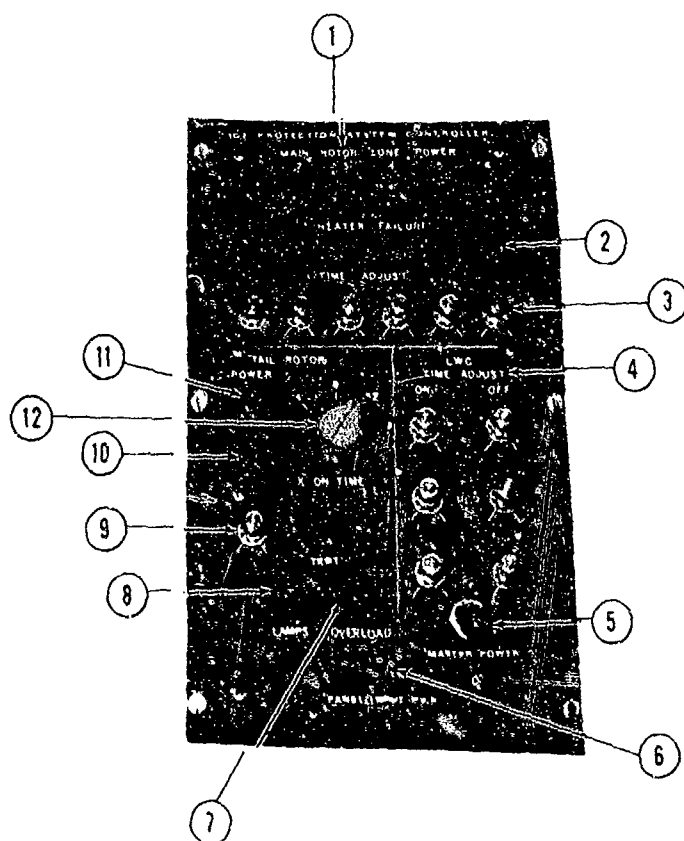
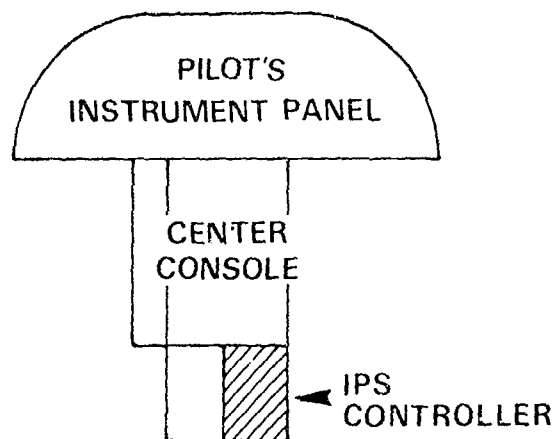


Figure 8. IPS Controller

Figure 8. IPS Controller (con't.)

INDEX	SWITCH OR INDICATOR	FUNCTION
1	MAIN ROTOR ZONE POWER	Provides indication when power is being applied to each of the six main rotor heated areas. As power is programmed to the main rotor heated areas, indicators come on and go off in sequence.
2	MAIN ROTOR HEATER FAILURE BITE	Provides indication of failure of one of the six main rotor heater elements.
3	MAIN ROTOR TIME ADJUST	Provides for individual adjustment of the heater-on time for each of the six main rotor heater elements. Locking nuts are provided to secure the settings.
4	LWC TIME ADJUST	Provides for the simultaneous adjustments of the time periods that all main and tail rotor heaters are off for light, moderate and heavy voltage settings.
5	MASTER POWER	Provides master power control for the ice protection system. Detented to prevent inadvertent operations. Must be cycled OFF, then ON to unlatch any failure lamps.
6	PANEL INPUT BREAKER	Controls 28 vdc power to the system. Provides protection against excessive current.
7	TEST OVERLOAD	Provides simulation of overload condition for preflight checkout of fault protection circuit.
8	TEST LAMPS	Provides test of all lamps on ice protection system control panel only.
9	TAIL ROTOR TIME ADJUST	Provides for adjustment of the heater-on time for the tail rotor heater elements.
10	TAIL ROTOR HTR FAIL BITE	Provides indication of a failure in the tail rotor deicing system.
11	TAIL ROTOR POWER	Provides indication that power is being applied to tail rotor heaters.
12	TAIL ROTOR OFF-TIME	Provides selection of tail rotor heater element off-time as 4, 8 or 12 times the heater element on-time.

Stabilizer Bar and Tip Weights

10. The stabilizer bar and tip weights are covered with electric heater blankets interconnected through flat braided wires to provide AC power for anti-icing. Stabilizer bar and tip weight heating is controlled by an ON/OFF switch on the IPS control unit with amperage monitoring provided by an ammeter located on the left center console.

Main Rotor Blade Deicing

11. The electrothermal deicing system of the main rotor blades uses sequentially supplied AC electric heating elements in the leading edges of the blades. The heated area is divided into six spanwise zones, each with its own heater element. Corresponding zones in both blades are heated simultaneously to provide symmetrical ice shedding. Heating begins at the blade tip zone and progresses sequentially to the root. The heater elements are covered with a stainless steel erosion shield bonded to the leading edge of the blades and are controlled by a switch located on the IPS control unit.

Ice Detectors

12. The IPS system incorporates a Leigh Instruments, LTD., MK 10 ice detector mounted on a 12-inch streamlined mast on the cabin roof (photo 1). The detector operates on the infrared occlusion principle, and consists of a light emitting diode/photo transistor assembly which provides an optical path that is partially occluded by the accretion of ice on the probe. The assembly is encased in an annular duct and ejection nozzle which is supplied with engine bleed air to induce high velocity air flow over the ice collecting probe and provide anti-icing. When the ice accumulation on the probe reaches a preset level, the probe is automatically electrically deiced and the cycle is repeated. The icing signals are displayed by lights and icing severity meters located in the cockpit. The signal is also routed to the IPS controller and integrating rate unit (IRU), for automatic control of main and tail rotor blade deice operation.

13. A Leigh MK 12 ice detector (photo 1) is located on the cabin roof at the pilot's air inlet. The MK 12 detector incorporates updated electronics from the MK 10 model, and like the MK 10 operates on the infrared occlusion principle and requires bleed air. A LWC display in gm/m^3 is provided for the MK 12 detector.

14. An ultrasonic type ice detector manufactured by Rosemount Engineering Inc. is attached to the copilot's air inlet on the cabin roof (photo 1). The detector utilizes a vibrating probe which is excited at its natural frequency by a magnetostrictive oscillator mounted on the end of the probe. As the probe accretes ice, the natural frequency is reduced and the change is detected as an ice accretion rate. When the ice thickness reaches a predetermined value the probe is automatically deiced and the cycle repeated. The icing probe is housed in an electrically heated aspirator shroud which uses engine bleed air to induce flow over the probe during low airspeeds. The icing signal is displayed on an LWC indicator located on the center console. The LWC indicator incorporates a manual selector knob which provides 5 damping levels to reduce needle oscillations.

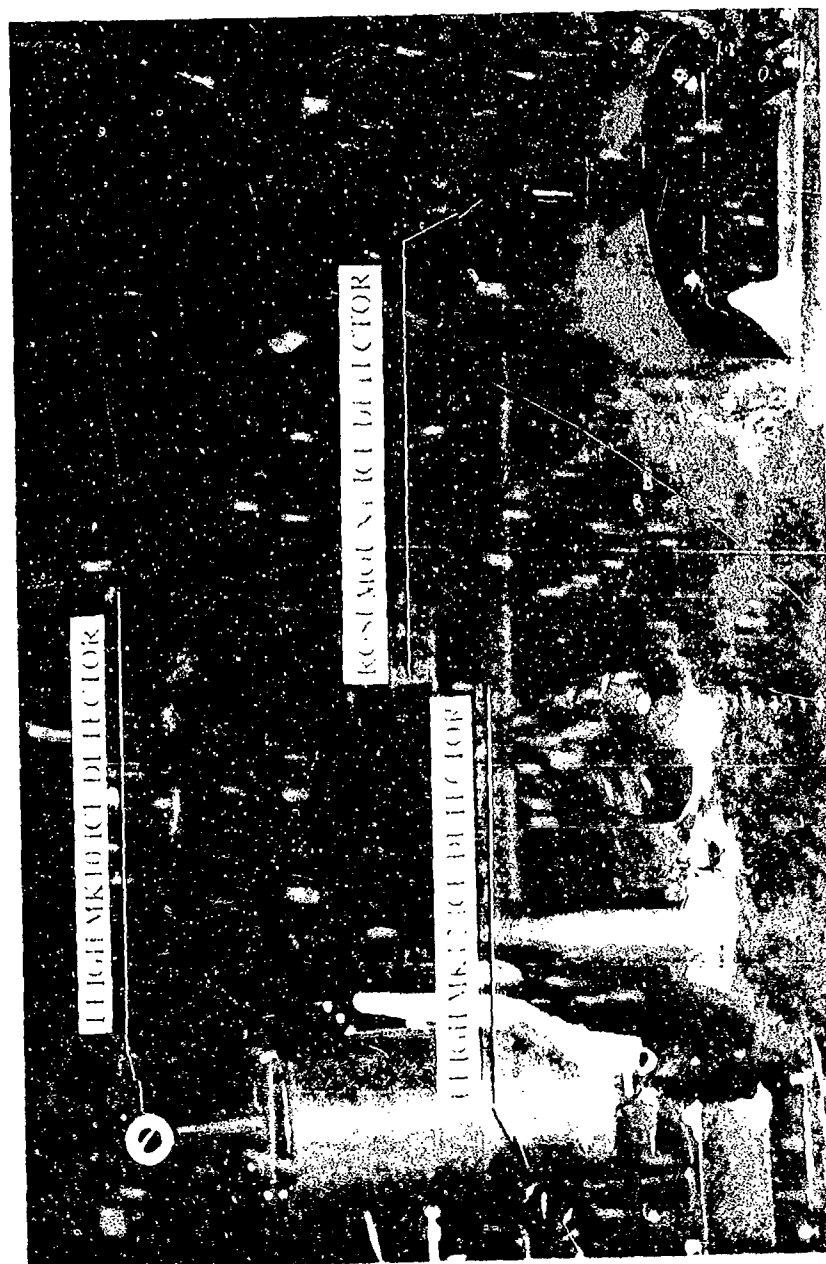


Photo 1. Ice Detectors

Integrating Rate Unit (IRU)

15. An integrating rate unit (Model IRU-4) (photo 2), manufactured by Leigh Instruments, Ltd., accepts the icing signal from the Leigh MK 10 ice detector and calculates this rate of ice accretion to indicate the amount of ice accreted up to the point where a new sample has been taken. The IRU accumulates the integrated blocks of accretion data and compares the total to a quantity which is preselected via thumbwheel switches. When the accumulated total exceeds that selected, a signal is produced which can be used to initiate a deice cycle, and illuminate a light on the IRU panel located in the crew compartment. An LWC display in gm/m^3 is also provided on the IRU panel.

Outside Air Temperature (OAT) Sensors

16. A Lewis OAT sensor is located flush mounted on the 12-inch streamlined mast on the cabin roof (collocated with the MK 10 ice detector). This sensor provides temperature signals to a dial indicator located on the IPS control unit and, when combined with LWC signals from the MK 10 ice detector, provide an indication of icing encounter by illuminating an ICING light on the IPS control unit. In addition, the signals are routed to the IPS controller for automatic blade deicing control.

17. A second Lewis OAT sensor is located on the left hand side of the vertical tail fin in the vicinity of the tail rotor. This sensor provides signals to a cockpit display and to the PCM tape system.

18. A Rosemount OAT sensor is located below the avionics compartment door on the nose of the aircraft. The sensor's sole purpose is to provide an additional signal which is displayed on the IPS panel OAT digital indicator.

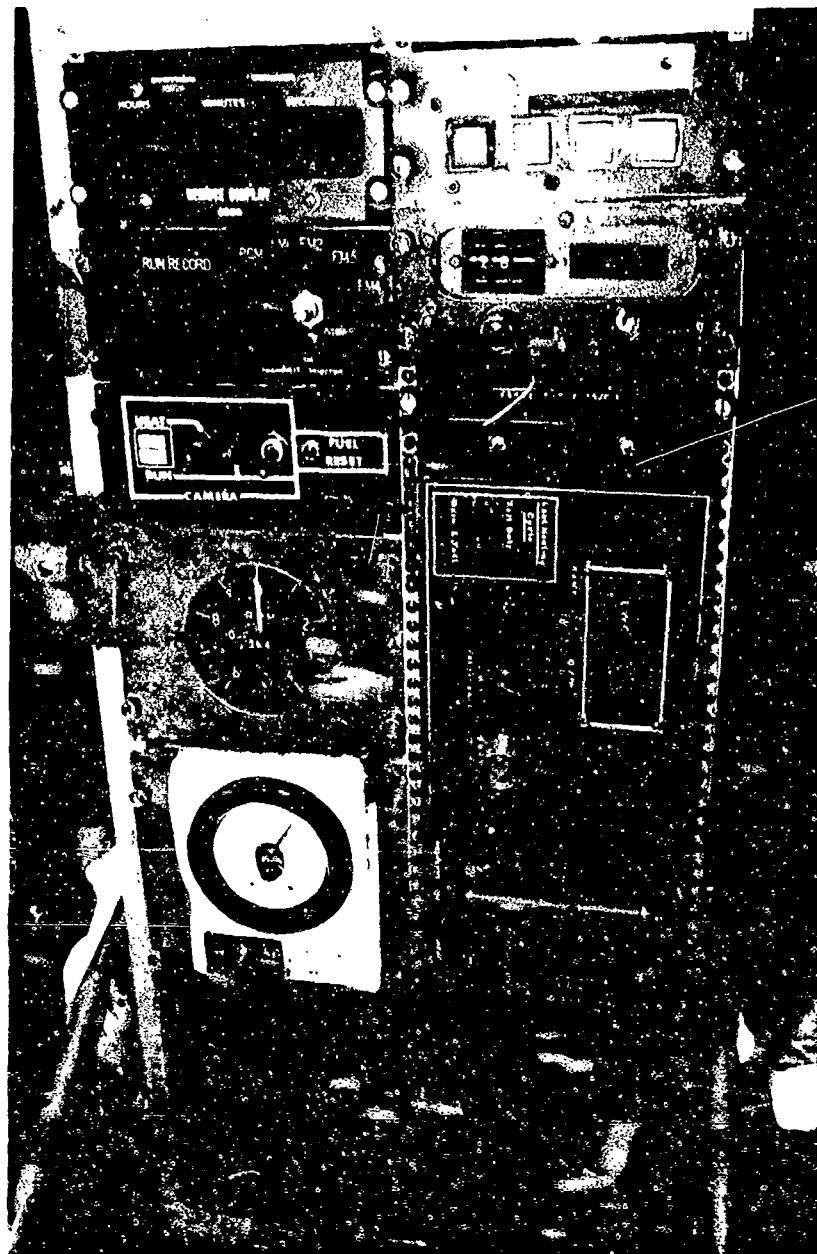


Photo Interpretive Photo Unit

APPENDIX C. INSTRUMENTATION AND SPECIAL EQUIPMENT

Instrumentation

1. The test instrumentation was installed, calibrated, and maintained by USAAEFA. Digital and analog data were obtained from calibrated instrumentation and were recorded on magnetic tape and/or displayed in the cockpit. The digital instrumentation system consisted of various transducers, signal condition units, an eight-bit PCM encoder, and an Ampex AR 700 tape recorder. Time correlation was accomplished with a pilot/engineer event switch and on-board recorded and displayed Inter-Range Instrumentation Group (IRIG) B time. Analog data were recorded on one track of the AR 700 recorder through the use of a voltage control oscillator (VCO). Various specialized test indicators displayed data to the crew continuously during the flight.

2. In addition to standard ship's instruments, the following parameters were displayed on calibrated test instruments in the cockpit:

- Airspeed (ship's)
- Altitude (ship's)
- Fuel flow
- Fuel used
- Engine torque
- Engine inlet screen differential pressure
- Main rotor speed
- Rosemount OAT
- Lewis OAT (vertical tail fin)
- Cambridge dew point temperature
- Rosemount LWC
- Leigh Mark 10 LWC
- Leigh Mark 12 LWC
- Leigh Mark 10 IRU
- Leigh ice detector bleed air pressure
- Rosemount ice detector bleed air pressure

3. The following parameters were recorded on magnetic tape.

PCM Parameters

- Control position:
 - Longitudinal
 - Lateral
 - Directional
 - Collective
- Engine torque
- Fuel flow
- Fuel used
- Airspeed (ship's)
- Altitude (ship's)
- Main rotor speed
- Engine inlet screen differential pressure
- Aircraft attitude:
 - Pitch
 - Roll
 - Yaw

Aircraft rates:

Pitch

Roll

Yaw

Outside air temperature

Rosemount LWC

Leigh Mark 10 LWC

Lewis OAT (vertical tail fin)

Cambridge dew point temperature

CG normal acceleration

Leigh Mark 10 IRU present sum

Leigh Mark 10 IRU last sum

FM Parameters

CG lateral acceleration

Pilot seat acceleration

Lateral

Vertical

Main rotor pitch link axial load

Tail rotor pitch link axial load

SPECIAL EQUIPMENT

Dew Point Meter

4. A Cambridge Model 137 chilled mirror dew point hygrometer (photo 1) is located on the cabin roof. This device samples airflow and indicates a corresponding dew point temperature to a cockpit display and to the PCM tape system.

Hub-Mounted Camera

5. A 16mm movie camera was installed on top of the main rotor slip ring housing canister (photo 2). The hub-mounted camera was designed to provide in-flight color photographic coverage of main rotor blade ice accumulation and shedding. The camera lens was electrically heated to prevent in-flight ice accumulation.

Ice Accretion Indicator Probe

6. A visual ice accretion indicator (photo 3) was mounted on the test aircraft to give the copilot a visual cue of ice buildup on the helicopter. It was composed of a small symmetrical air foil (OH-6A tail rotor blade section) with a 3/16-inch diameter steel rod protruding 1 1/2 inches out from the leading edge at the center. The protruding rod was painted with multi-colored 0.2-inch stripes to provide a reference for ice thickness estimation. The unit was mounted on the copilot's door facing forward.

Meteorological Research Incorporated (MRI) Equipment

7. The test objectives requiring cloud parameter data (LWC and droplet size distribution) were obtained through MRI instrumentation. The following equipment was installed on the test aircraft: an axially scattering probe (ASP) (photo 4), a

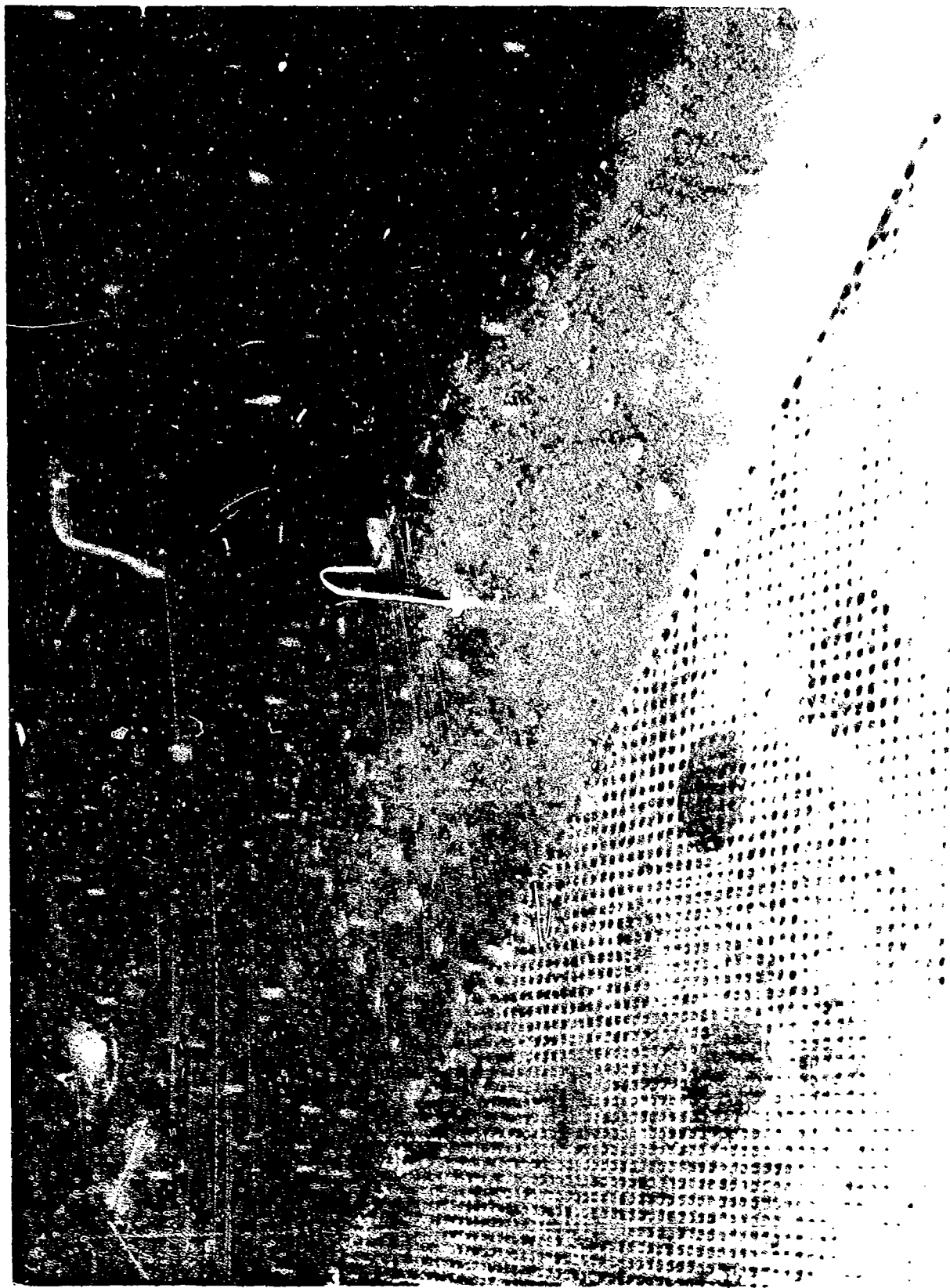
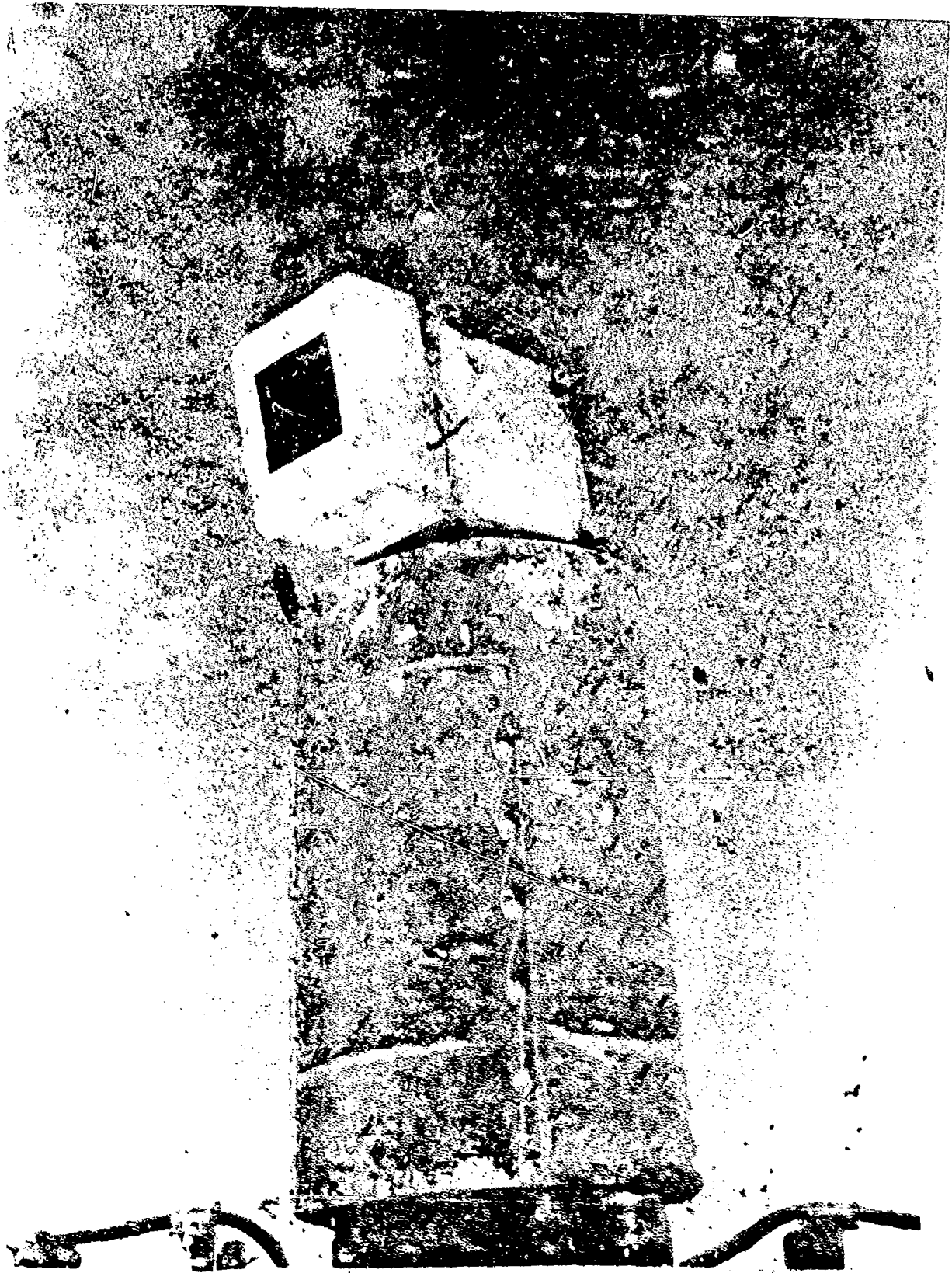
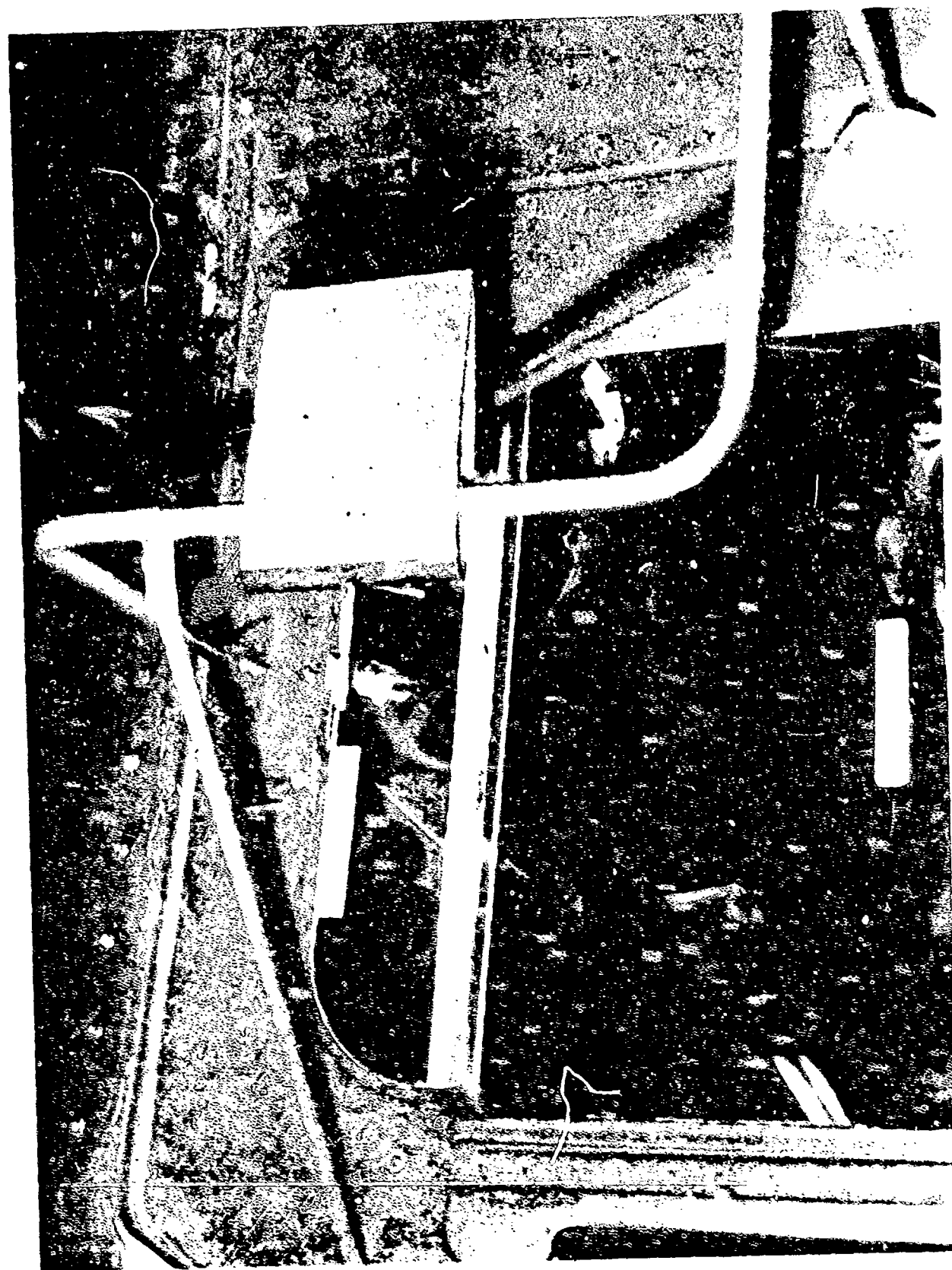
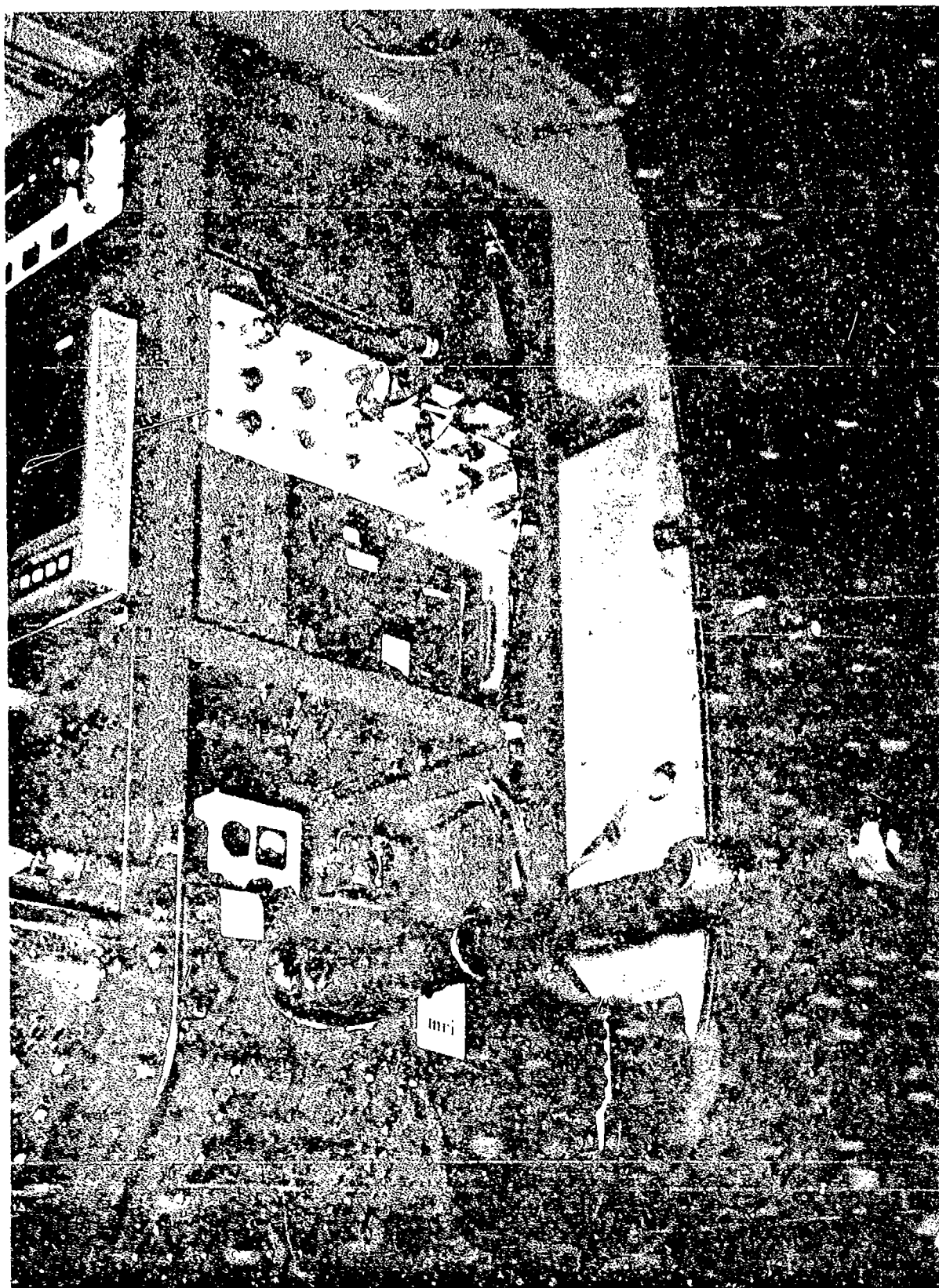


Photo 1. Dye spot Heteromorph







cloud particle spectrometer (CPS) (photo 5), and associated recording equipment (photo 6).

8. The ASP sizes particles by measuring the amount of light scattered into the collecting optics aperture during particle interaction through a focused laser beam. The signal pulses are AC coupled to a pulse height detector which compares their maximum amplitude with a reference voltage derived from a separate measurement of the DC light signal illuminating particles. The system is capable of sizing particles from 2 to 30-microns diameter having velocities from 10 to 125 m/sec (20 to 240 kts).

9. In the CPS, particles are sized using a linear array of photodiodes to sense the shadowing of array elements by particles passing through its field of view. Particles are illuminated by a helium-neon laser. As shadowing of each photodiode element is dark enough, a flip-flop memory element is set. The particle size is determined by the number of elements set by a particle's passage, the size of each array element, and the magnification of the optical system.

10. Two different CPS probes were used during this evaluation. One probe contained 24 active photodiode elements capable of sizing into 15 size channels with a magnification set for a size range of 20 to 300 microns. The other probe contained 20 photodiode elements capable of sizing into 15 size channels with a magnification set for a size range of 140 to 2100 microns.

11. More detailed descriptions of the ASP and CPS are contained in reference 2, appendix A.

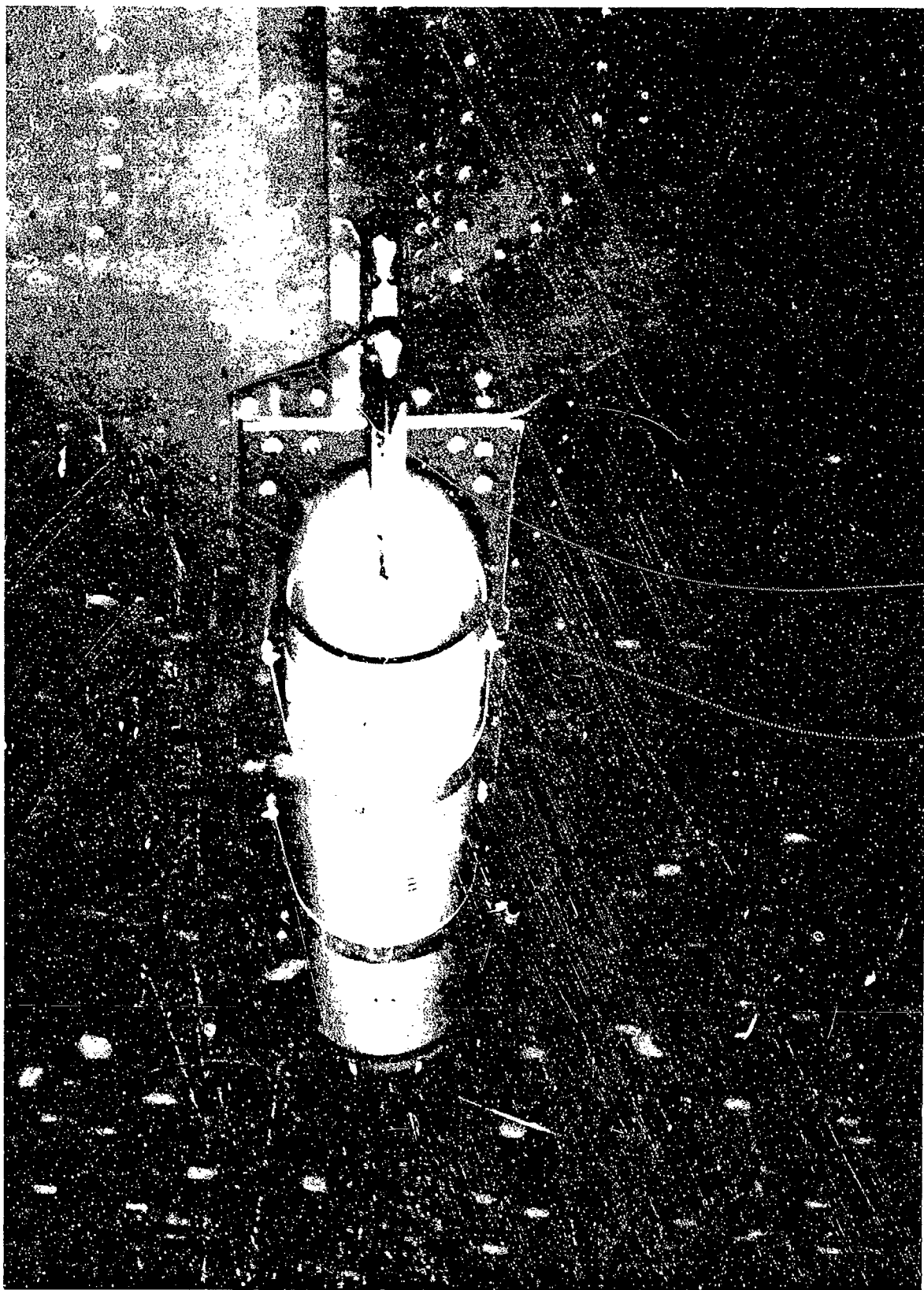


Photo 5. Cloud Particle Spectrometer

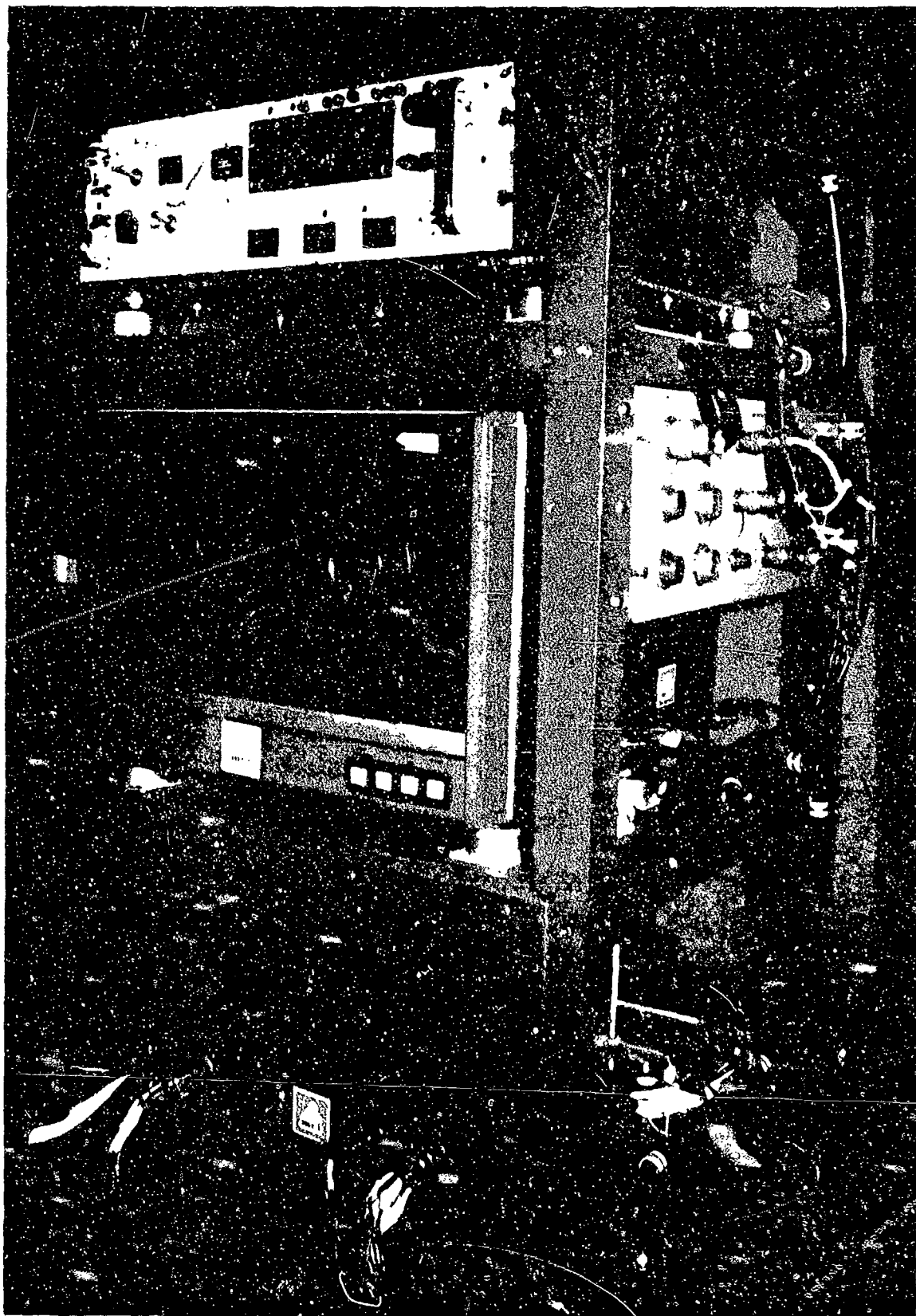


Photo 6 MRI Instrumentation Package

APPENDIX D. TEST TECHNIQUES AND DATA ANALYSIS METHODS

GENERAL

1. The procedure used to collect data was the same throughout the test. All standard UH-1H anti-ice systems except the copilot's windshield were activated prior to entering expected icing conditions. After entering the cloud, altitude was varied until maximum icing indications were observed on the LWC indicators. Once established on the test altitude, baseline level flight performance data were obtained.
2. The aircraft was flown in the icing cloud until fuel requirements necessitated returning to base. Prior to exiting the cloud, level flight performance data were again obtained to determine degradation due to ice accretion.

Ice Accretion

3. Ice accretion was monitored in-flight by the copilot using the visual ice accretion indicator probe. The engineer monitored time in cloud, LWC indications, and IRU counts to correlate accretion rates.
4. Main rotor blade ice accretion was documented using a high-speed motion picture camera mounted on the main rotor slip ring housing canister. Photographs taken from the chase aircraft in visual meteorological conditions and postflight photographs were used to document the ice remaining on test aircraft components.

Level Flight Performance

5. Level flight performance data were obtained by establishing trim level flight at the test airspeed (90 KCAS), altitude, and OAT. Data were recorded before and after the cloud immersion.
6. Level flight performance degradation due to ice accretion was assessed by comparing the engine power required to maintain constant airspeed and altitude before and after icing. Power required was corrected for fuel burn-off by using the nondimensional level flight performance carpet plot (ref 8, app A) for a standard UH-1H.
7. Engine inlet screen differential pressure was monitored during the icing flights to determine the effects of ice accretion on the inlets.

Vibration

8. Aircraft vibration was qualitatively evaluated by the aircrew and quantified using the FM data system. Data tapes from the on-board FM data system were analyzed using a Spectral Dynamics 301 real time spectral analyzer and a Spectral Dynamics 302B ensemble averager. The Vibration Rating Scale (VRS), presented in figure 1, was used to augment crew comments on aircraft vibration levels during main rotor asymmetric ice sheds.

Weight And Balance

9. Prior to testing, the aircraft gross weight and longitudinal center of gravity were determined by using calibrated scales. The longitudinal CG was calculated by a summation of moments about a reference datum line (FS 0.0). All airframe modifi-

DEGREE OF VIBRATION	DESCRIPTION ¹	PILOT RATING
No vibration		0
Slight	Not apparent to experienced aircrew fully occupied by their tasks, but noticeable if their attention is directed to it or if not otherwise occupied.	1 2 3
Moderate	Experienced aircrew are aware of the vibration but it does not affect their work, at least over a short period.	4 5 6
Severe	Vibration is immediately apparent to experienced aircrew even when fully occupied. Performance of primary task is affected or tasks can only be done with difficulty.	7 8 9
Intolerable	Sole preoccupation of aircrew is to reduce vibration level.	10

¹Based upon the Subjective Vibration Assessment Scale developed by the Aeroplane and Armament Experimental Establishment, Boscombe Down, England.

Figure 1. Vibration Rating Scale

cations and test instrumentation installations were completed prior to weighing.

MRI CALCULATION OF LWC

10. The output from the laser nephelometers was in terms of the number of particles in each size channel. These data were then used to calculate the LWC and mass distribution of each sample point by the following equation.

$$LWC = w \frac{4\pi}{3} \sum_{i=1}^n \left(D_i/2 \right)^3 N_i \quad (1)$$

Where:

w = Density of liquid water

D_i = Mean diameter for the i th channel

N_i = The number of droplets in the i th channel

n = Number of channels

Mass distribution is the droplet concentration weighted by the mass of the droplet of the appropriate size,

$$m_i = \frac{\pi}{6} D_i^3 \times w \quad (2)$$

then

$$M_i = P_i \times m_i \quad (3)$$

Where

M_i = Quantity plotted as droplet mass

P_i = Droplet concentration

m_i = Mass of droplet of size observed in channel i

APPENDIX E. TEST DATA

INDEX

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Ice Detector Comparison	2
Main Rotor Asymmetric Shed Occurrence	3

Table 1. Natural Icing Summary

Flight Number ⁷	Outside Air Temperature (°C)	Rosemount LWC ¹ (gm m ⁻³)	Leigh Mk 10 LWC (gm m ⁻³)	Leigh Mk 12 LWC (gm m ⁻³)	ASP ² LWC (gm m ⁻³)	Immersion Time (minutes)	Immersion IRU ³ Counts	Torque Rise (psi)	Visual Ice Accretion ⁵ (inches)
14	-12.0	0.12	0.13	0.15	0.14	5.5 ⁴	164	None	0.1
	-12.5	0.37	0.22	0.20	0.32	5.0 ⁵	371	2.0	0.3
16	-4.5	0.32	0.21	0.26	0.29	50.0	1362	2.2	1.2
17	-12.0	0.13	0.13	0.14	0.17	55.5	933	None	0.8
18	-10.0	0.24	0.17	0.20	N/A ⁶	25.5 ⁵	557	None	0.5
		0.25	0.15	0.20		24.0 ⁵	480	None	0.8
		0.29	0.17	0.18		15.0 ⁵	332	None	1.4
20	-4.0	0.13	0.11	0.15	N/A	70.0	491	None	0.6
21	-4.5	0.17	0.14	0.15	0.21	30.0 ⁵	834	1.5	0.7
23	-2.0	0.09	0.05	0.06	N/A	13.0	51	None	0.2
25	-9.0	0.31	0.24	0.26	0.17	36.0 ⁵	675	3.0	0.9
		0.47	0.27	0.33	0.32	7.0 ⁵	235	None	1.0
		0.46	0.27	0.34	0.30	12.0 ⁵	406	None	1.4
26	-9.0	0.13	0.11	0.14	0.10	70.0	973	None	0.8
28	-4.5	0.18	0.15	0.16	0.12	54.0	1047	2.0	0.9

¹ LWC = Liquid water content² ASP = Axially scattering probe³ IRU = Integrating rate unit⁴ Obtained from visual ice accretion indicator probe mounted on copilot's door⁵ Occurrence of asymmetric shed⁶ N/A = Not available⁷ Flight numbers correlate with data in reference 2

FIGURE 1
MAIN ROTOR ASYMMETRIC SHED OCCURRENCE
JUN-01-05A 5/11 70-16318

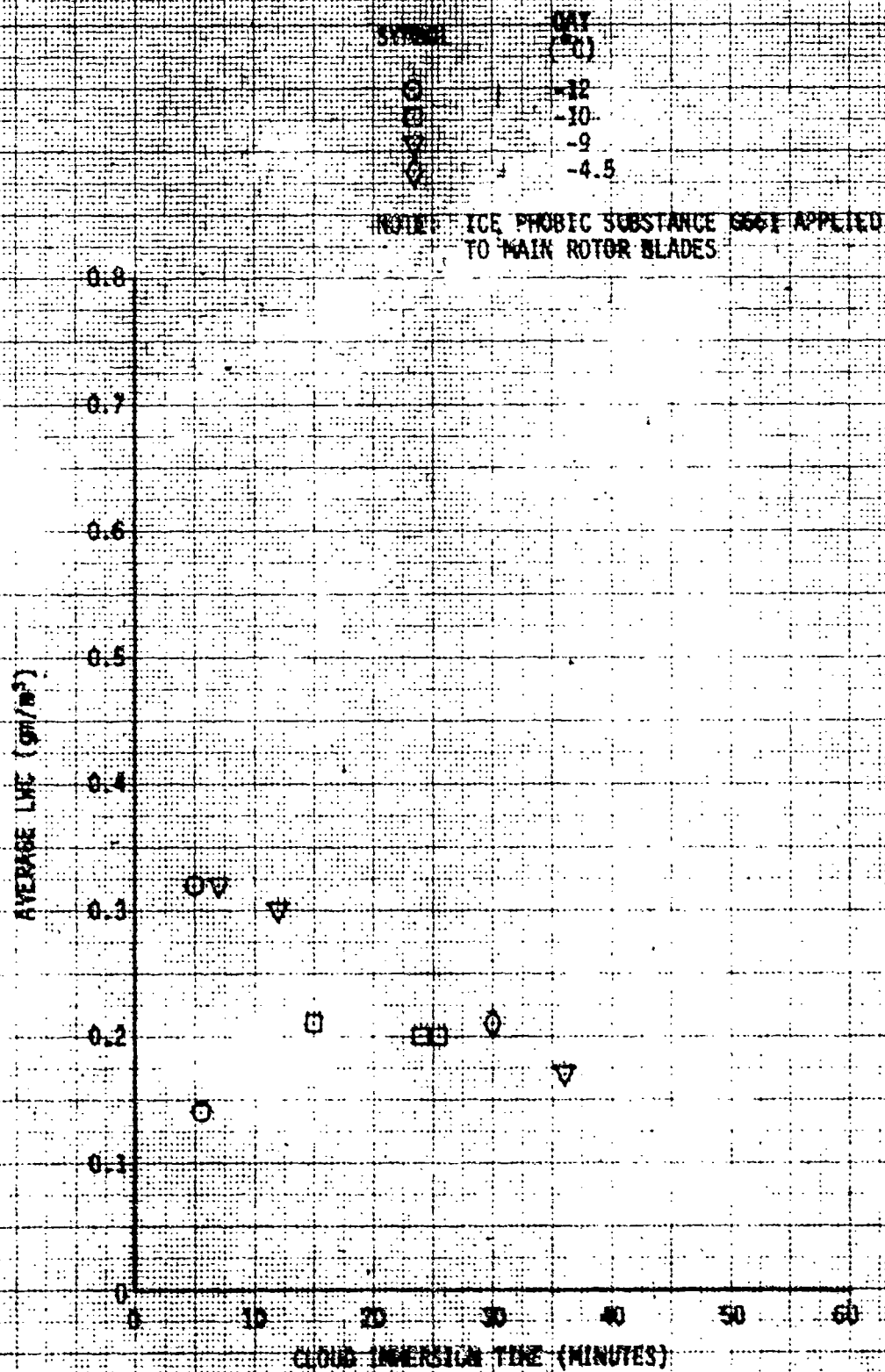


FIGURE 2
ICE DETECTOR COMPARISON
JUN-14 10A 8/N 7D-16318

AVG
GROSS
WEIGHT
(LB)
8140

AVG
CG LOCATION
LONG
(PS)
136.0 (M10) 0.1 (M10)

AVG
DENSITY
ALTITUDE
(FT)
3280

AVG
OAT
(°C)
-4.5

AVG
ROTOR
SPEED
(RPM)
324

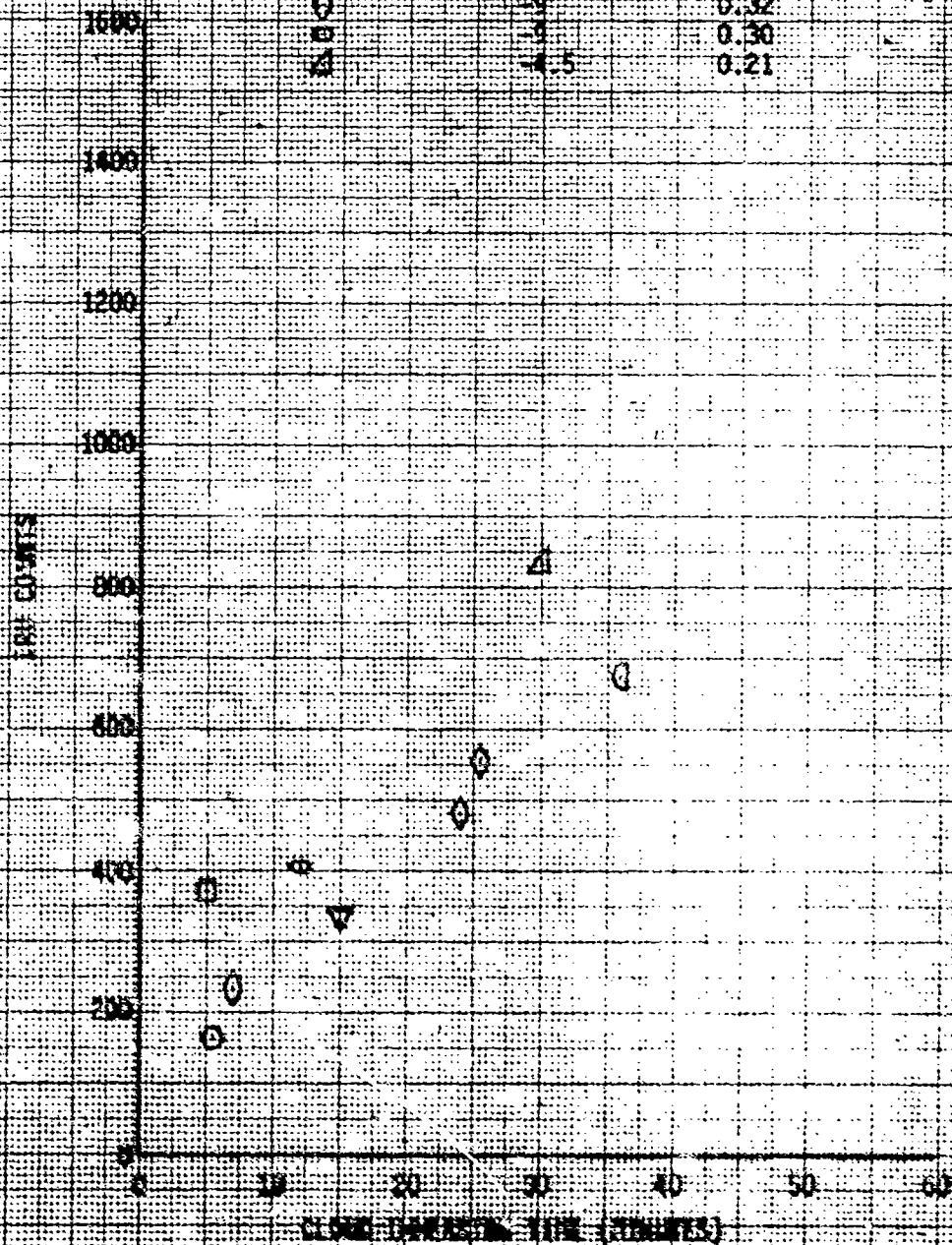
ASP
ROSE MOUNT
LEIGH MK 10
LEIGH MK 12

LIQUID WATER CONTENT
(g/m³)

CLOUD IMERSION TIME (MIN)

Figure 2
 WASH STATE UNIVERSITY OPEN OCCURRENCE
 JULY-SEP 1964 S.W. 70-16318

STATION	AVG OAT (°C)	AVG LWC (g/m ³)
1	13	0.14
2	12.5	0.32
3	10	0.20
4	10	0.21
5	9	0.17
6	14	0.32
7	13	0.30
8	14.5	0.21



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Deputy Chief of Staff for Research Development and Acquisition (DAMA-PPM-T, DAMA-RA, DAMA-WSA)	3
Comptroller of the Army (DACA-EA)	1
US Army Materiel Development and Readiness Command (DRCDE-DH, DRCQA-E, DRCRE-I, DRCDE-RT)	4
US Army Training and Doctrine Command (ATTG-U, ATCD-T, ATCD-ET, ATCD-B)	4
US Army Aviation Research and Development Command (DRDAV-DI, DRDAV-EE, DRDAV-EG)	10
US Army Test and Evaluation Command (DRSTS-CT, DRSTS-AD)	2
US Army Troop Support and Aviation Materiel Readiness Command (DRSTS-Q)	1
US Army Logistics Evaluation Agency (DALO-LEI)	1
US Army Materiel Systems Analysis Agency (DRXSY-R)	1
US Army Operational Test and Evaluation Agency (CSTE-POD)	1
US Army Armor Center (ATZK-CD-TE)	1
US Army Aviation Center (ATZQ-D-T, ATZQ-TSM-A, ATZQ-TSM-S, ATZQ-OT-AU)	4
US Army Combined Arms Center (ATZLCA-DM)	1
US Army Infantry Center (ATSH-TSM-BH)	1
US Army Safety Center (IGAR-TA, IGAR-Library)	2

US Army Research and Technology Laboratories/ Applied Technology Laboratory (DAVDL-ATL-D, DAVDL-Library, DAVDL-ASA)	4
US Army Research and Technology Laboratories/ Aeromechanics Laboratory (DAVDL-AL-D)	1
US Army Research and Technology Laboratories/ Propulsion Laboratory (DAVDL-PL-D)	1
Defense Technical Information Center (DDR)	12
Federal Aviation Administration	50